TAMPEREEN TEKNILLINEN YLIOPISTO

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BIM BASED INSTALLATION LOGISTICS FOR MODULAR POWER PLANT CONSTRUCTION

Master of Science Thesis

Examiner: Professor Kalle Kähkönen
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ABSTRACT

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Building information modelling has proven to be an effective tool for both engineering and construction management. It can be used from early conceptual design to detailed design and for creating construction phase models. It is also a practical tool for managing communication and other data between Designers, Constructor, Fabricators and Contractors.
This Master's thesis is a company specific case study and written for localizing potential in more BIM based project management. Main objective of the research is to formulate a sketch of a suitable BIM based installation logistics and project management system focusing on packing management system and packing order. The research has been delimited to pertain steel frame elements of power plant engine hall.
In order to achieve the main objective, installation logistics and other construction management related properties of the chosen softwares Tekla Structures and Tekla BIMsight are examined. Main interests of the constructor company concerning construction management and especially installation logistics are also localized. Furthermore, quality standards for modelling and packing process are defined to achieve the main objective. As a result, findings of the research and suggested tools are evaluated based on the needs of the constructor.
Tekla Stuctures can be used for conceptual design, for generating drawings and report, and for erection scheduling. In addition, it has turned out to be practical software for managing frame element delivery and data needed for site management. Organizer found in Tekla Structures especially is a handy tool for managing information needed for coordination of a site and frame element delivery.
Tekla BIMsight is software for project collaboration and can be used for combining the models of different project stakeholders and for frame element unloading and installation management. Tekla BIMsight is a practical tool for making assembly plans and progress reports of site installation works. It can also be used for the supervision of installation works, for frame element unloading and grouping, and for on-site collaboration between structural and MEP works. Use of note files compatible to Tekla Structures and Tekla BIMsight enables BIM based communication between Structural Designers, Project Engineers and Site Supervisors throughout the project.
The best way to ensure a practical frame element packing order is to attach an installation sequence number pointing out the required packing order for each steel assembly and to publish these numbers in an assembly list. It is also practical to divide an engine hall for modules and phases if needed using the Organizer tool in Tekla Structures, and to utilize this division for managing frame element delivery. Still, for developing installation logistics further, it is recommendable to seek better frame installation management through more integrated BIM based communication protocols.

TIIVISTELMÄ

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Tietomallintaminen on osoittanut tehokkaaksi tavaksi hallita suunnittelua ja rakentamista. Sitä voidaan hyödyntää konseptitason suunnittelusta detaljitason suunnitteluun ja rakennusvaiheen mallin tuottamiseen. Tietomallipohjaisuus soveltuu toisaalta myös suunnittelijoiden, rakennuttajan, toimittajien ja urakoitsijoiden välisen kommunikaation ja muun tiedon hallintaan.
Tämä diplomityö on luonteeltaan toimeksiantajayritykseen liittyvä case tutkimus jossa kartoitetaan tietomallintamisen käytön hyödyt ja mahdollisuudet projektinhallinnan kannalta. Tutkimuksen päätavoite on muodostaa luonnos tarkoituksenmukaisesta tietomallipohjaisesta asennuslogistiikka- ja projektinhallintajärjestelmästä ja erityisesti tietomallipohjaisesta pakkausjärjestelmästä ja -järjestyksestä. Tutkimus on rajattu käsittelemään voimalaitoksen konehallin runkoa.
Päätavoitteen saavuttamiseksi tutkitaan kahden valitun ohjelman, Tekla Structures:n ja Tekla BIMsight:n, ominaisuuksia asennuslogistiikan ja muun rakentamisen hallinnan kannalta. Lisäksi kartoitetaan työn toimeksiantajayrityksen tavoitteen edellä mainittuihin näkökohtiin liittyen. Tämän ohella määritellään päätavoitteeseen tähtäävät laatustandardit mallintamiselle ja elementtien pakkausprosessille. Lopputuloksena arvioidaan löydösten merkittävyyttä toimeksiantajan tavoitteiden perusteella.
Tekla Strutures ohjelmaa voidaan käyttää konseptitason suunnittelussa, piirustusten ja raporttien luonnissa sekä asennustöiden aikataulutuksessa. Se on myös käytännöllinen työkalu rungon toimitukseen sekä työmaan hallintaan tarvittavan tiedon luomiseen. Ohjelman Organizer-työkalu on osoittautunut erityisen hyödylliseksi työmaan ja elementtitoimituksen koordinointiin tarvittavan tiedon hallintaan.
Tekla BIMsight ohjelma mahdollistaa projektiyhteistyön ja eri suunnittelualojen tietomallitiedon yhdistämisen. Ohjelma on käytännöllinen tietomallipohjaisten asennussuunnitelmien ja –raporttien tekemiseen. Lisäksi se soveltuu asennustöiden ohjaukseen, elementtien purkamiseen konteista ja elementtien ryhmittelyn hallintaan sekä rakenneteknisten ja talotekniikkaan liittyvien töiden yhteensovittamiseen. Tekla Structures ja Tekla BIMsight ohjelmien kanssa yhteensopivat note-tiedostot mahdollistavat tietomallipohjaisen viestinnän suunnittelijoiden ja projekti-insinöörien sekä projekti-insinöörien ja työnjohdon välillä.
Pakkausjärjestyksen osoittavan teräselementtikohtaisen asennusjärjestysnumeron käyttö asennuslistassa on paras tapa varmistaa tarkoituksenmukaisen pakkausjärjestyksen toteutuminen. Tietomallitiedon ja elementtitoimituksen hallinnan kannalta on myös järkevää jakaa konehalli moduuleihin ja tarvittaessa rakennusvaiheisiin Organizer-työkalua apuna käyttäen. Teräselementtirungon asennuslogistiikan jatkokehityksen kannalta olisi kuitenkin suositeltavaa keskittyä tietomallinnuksen kommunikaatiotyökalujen pidemmälle vietyyn soveltamiseen kohdeyrityksessä.

PREFACE

This Master of Science Thesis has been written for the Department of Civil Engineering at the Tampere University of Technology. The thesis is a separate development project funded and employed by Wärtsilä Finland Oy and was implemented in the year 2014. Instructor of the thesis was Engineering Manager Simon Nyman from Wärtsilä and examiner Professor Kalle Kähkönen from Tampere University of Technology.

I am applying my gratitude for all the stakeholders that have been involved in my thesis. Special thanks I will apply to my instructor Simon Nyman who gave the idea for the subject of the thesis. He has also had a major role in defining the needs of the company and the course of my research.

In Vaasa 4.11 2014

Matias Humalamäki

TABLE OF CONTENTS

TERMS AND DEFINITIONS

Assembly	Modeling unit consisting of one or several modeling parts or items jointed together using, for example, welds or bolts. [1]
BIM	Building Information Modeling, process for creating a digital representation of physical and functional characteristics of a facility or a building. [2]
GUID	Global Unique ID, object specific mark that identifies object regardless the used application. [3]
IFC	Industry Foundation Classes, an international public and platform neutral file format for presenting building information. [3]
IPD	Integrated Project delivery, BIM based holistic approach for construction process in a form of collaboration among the owner, the prime and possibly sub designers, the prime and possibly sub-contractors; takes place from early design continuing through the project handover. [3]
Item	A building 3D shape object that is created in an external modeling software and available in Tekla Structures shape catalog. [1]
Logwis	An internal software between Wärtsilä and suppliers, and between project and site teams for managing deliveries and logistics.
Lotting	Evaluating specific model parts with respect to the number of units that can be carried by a container or a transport vehicle. [1]
MASP list	Material Specification list, a list that is used for expressing total weight of all main steel assembly entities such as building or modules, also used for setting the division of deliveries for a frame element supplier.

Engine hall module	Engine hall entity that is used for splitting a large building for practical areas. Same division is also used for managing assembly lists.
Object	A separate modeling unit and a repository of information holding data regarding 2D and 3D geometry description of the actual component or product [4]. It can be part, assembly or some other modeling unit.
Part	A basic modeling unit or building object describing workshop part such as main profile, bolt or plate; consists of 2D profile that is extruded for indicating erection sequence. [1]
Phase	Specific period during which the construction is planned to complete, In Tekla Structures phases are used for breaking up model into sections and can also be used for indicating erection sequences [1].
Engine hall section	Stretch of gridlines between two columns in lengthwise direction of an engine hall.
Tare weight of a container	Weight of an empty container.

1 INTRODUCTION

1.1 Background of the research

Employer for the research is Wärtsilä Finland Oy. Master thesis is based on the need to evaluate how BIM technology could be utilized in construction phase processes, especially in frame element packing and installation management. Based on the results of the research, the company will evaluate the need and timing for changes in its procedures. Master thesis will also provide basic information of the nature of BIM for the employees.

The current situation in the company is that there is no standardized way to manage the frame element packing order. At the moment, whether the element packing order is defined or not depends on separate project specific requirements set by the project team. Main reason for commissioning the research is to improve and unite current frame element packing management to be more accordant with the frame installation sequence.

Since the power plants made by Wärtsilä are sold as engine-based modules for the customer, management of frame installation logistics should also be based on the modularity. Created system and gathered information should also be utilized in other process of the company. This is sought through creating standardized system.

The company doesn't use BIM in project and construction management in broad scale at the moment. Navisworks Freedom is used for checking design collaboration and other design related issues by Project Engineers. It is also available for site teams for on-site collaboration between structural and MEP works. Engineering company taking care of design work of Wärtsilä is using BIM-based design softwares for civil, mechanical and electrical design and for combining the separate models of these scopes together. Civil structural designers are using Tekla Structures for structural modelling, while combined models used for design collaboration is created in Navisworks Manage. The company is using Microsoft Project for project scheduling.

1.2 Objectives of the research

The main objective of the research is to formulate a suitable BIM based packaging management system and packing order with suitable installation logistics and project management system for the modular engine hall frame, so that erection of the steel frame would be easier and quicker to accomplish. It should also be compatible for the current frame installation systems what it comes to the management of time and erection order. Furthermore, it is studied whether it is practical to manage installation logistics and project in general based more on BIM technology.

One of the sub-objectives is to report main interests of the constructor concerning BIM in construction management, especially in installation logistics. Another sub-objective is to make a research of logistics and other construction management based properties of two Tekla softwares, Tekla Structures and Tekla BIMsight. One sub-objective is also to define quality standards for the modelling and packing process, so that by following these standards frame installation would intensify. Findings and the suggested logistical tools will be evaluated based on the needs of the company at the end of the research. Main objective with sub-objectives of the research are shown in Figure 1.1.

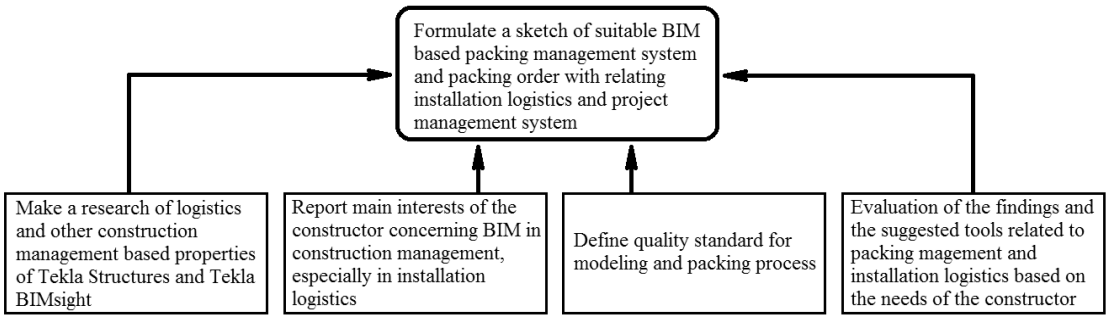


Figure 1.1 *Main objective and sub-objectives of the master's thesis.*

Although there is usually several different buildings in power plant area, only steel frame of and engine hall is taken into account in this research. One engine hall is usually consisting of one or several different engine hall modules and other separate rooms between or outside these engine hall modules. BIM based frame installation scheduling and time consumed for each installation phase is not handled in this thesis.

1.3 Reseach methods

The content of this thesis is based on a literature review, interviews of different project stakeholders and software testing. Literature review will provide basic knowledge of studied softwares, Tekla Structures and Tekla BIMsight. It is also explaining main features and benefits of BIM based process.

The interview of Wärtsilä's main frame element supplier will specify manufacturing and packing related capabilities and needs of the supplier. It is also reporting current manufacturing and packing protocols. Although there are also several other frame element suppliers delivering their goods at Wärtsilä's sites, only the main frame element supplier is considered in this thesis. The reason for this is that the supplier takes care or great majority of the deliveries.

Interviews allocated to Site Supervisors, Section Managers and Chief Project Engineers are introducing current frame element unloading and installation related protocols, and needed improvements for these protocols. The interview of a Structural Designer of will specify software versions used in Wärtsilä's projects by the assigned engineering

company. Current modelling procedures and ways to utilize modelling information by the engineering company are also introduced.

Tekla Structures is tested for finding the most practical tools for producing and managing information related to frame element packing and installation management. Tekla BIMsight is studied in practice in order to report software properties that are most useful for managing frame element installation and unpacking by the constructors. It is also studied how to collaborate between these two softwares.

Software versions to be tested in the research are Tekla Structures 20.0 and Tekla BIMsight 1.9.2. As a result, some of the software properties to be introduced are only available in the tested versions and the information must be adapted if old software versions are used.

The structure of the thesis is the following:

Chapter 2 provides basic knowledge of the subject and required information needed for understanding content of the research.

Chapter 3 presents main properties of two softwares used in the thesis, Tekla BIMsight and Tekla Structures, in order to create a picture of feasibility of these softwares.

Chapter 4 describes the research methods used for determining a solution for the research problem.

Chapter 5 presents current modelling, installation and packing systems based on the interviews of the project stakeholders.

Chapter 6 describes the needs and capabilities to improve current installation and packing system based on the interviews of the project stakeholders.

Chapter 7 presents BIM based communication tools and protocols of Tekla Structures and Tekla BIMsight.

Chapter 8 presents frame installation simulation tools of Tekla BIMsight and Tekla Structures.

Chapter 9 describes the properties of the two softwares for frame packing and installation management.

Chapter 10 presents the results of the research by providing a summarized proposal of the content of BIM based installation logistics and related project management system.

Chapter 11 describes possible sources of error, deviations from the expected results and reliability of the research, and provides a conclusion based on the findings and assess the need for a future research.

2 UNDERSTANDING BIM

Building Information Modeling (BIM) is a process that aims at creating a digital representation of physical and functional characteristics of a facility or a building. [2] It is used in the field of the architecture, engineering and construction industries. This technology supports design through its phases, which allows higher quality analysis and control compared to the manual processes. When the modeling and all the related processes are done, these computer generated model will contain precise geometry of the building to be realized. In addition, model will include data related to construction, fabrication and procurement activities. [3]

BIM also provides large scale of tools that are needed for modeling the lifecycle of a building. Adapting BIM in construction and design process is often changing the roles and relationships among a project team by providing the basis for new design and capabilities in construction. When BIM process is adopted well, BIM facilitates better quality buildings with lower cost and reduced project duration by more integrated design and construction process. [3]

There is more information available in early stage of the project when using BIM in process management. More options can also be reviewed at the beginning of the project. On the other hand, influence of the made decision is at its peak at the early stage of a project. Therefore use of BIM reduces risks in the project. Benefits of BIM based process management in project life-cycle are presented in Figure 2.1. [5]

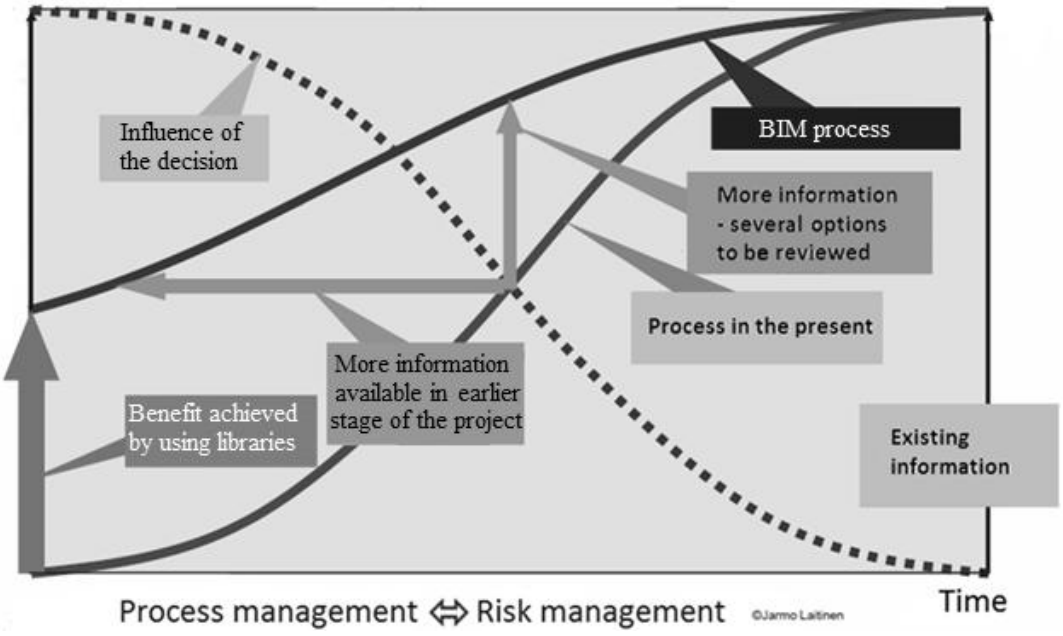


Figure 2.1 *Benefits of BIM based process management in project life-cycle* [5].

2.1 BIM for Engineers in different phases of the project

2.1.1 Conceptual design

BIM process starts often in a conceptual design phase, which sets the requirements of spatial area, functions, type of construction and the basic evaluation of functional and economical viability of the building. Architects and other early stage participants are using 3D tools for sketching based on massing studies of the building. In addition, modeling softwares along with the analysis softwares enables following functions among other things:

- Lighting simulations
- Energy analysis
- Acoustic analysis
- Sun shading
- Heat loss and gain
- Heating and cooling loads
- Capital cost estimations
- Building evacuation. [3]

Although beneficial in the conceptual design, BIM tools don't reply all the functions needed for general concept design. None of the softwares available in market does reply on full scope of the BIM based conceptual design. There is also usually lots of information out of the reach of modeling affecting to the decisions made in the early phases of the project. In addition, much of the analyses are carried with secondary analysis tools, not by BIM design tools. [3]

2.1.2 BIM in detailed design

Based on the possible conceptual design models or other documents, a large scale of modeling softwares with different functions are available on market. Collaboration between these applications is enabled by global IFC standard. System design softwares are related to the modeling and analysis in the field of structural design, energy analysis, mechanical and equipment analysis, lightning simulations, acoustic analysis, air flow analysis and building functional analysis. In addition to the design model created for multiple purposes, there are analysis models based on the design model for software specific analyses. [3]

BIM based detailed design enables accurate and automatically computed quantity definitions, such as volumes and areas of the structures. Specified data extracted from BIM design tool enables detailed and accurate information of building products and material quantities used in cost estimations, including target costing. This also elimi-

nates traditional conduct and related adverse effects of removing cost items at the final stages of the project. [3]

2.1.3 Construction level building models

Construction level building models can be based on three types of modeling process: models are created by contractors based on non-model based documents, construction and fabrication models are based on predefined detailed design models, or the contractors and fabricators are part of the modeling process from the beginning of detailed design. For creating fully integrated BIM design process, the last one of the mentioned modeling processes is the most recommendable concept. This Integrated Project Delivery (IPD) consisting of sharing models between designers and builders, and developing them by utilizing close collaboration. This will help the project to meet owner requirements at significantly reduced time and cost. [3]

In many cases, drawing generation is one of the biggest functions of construction level models at the moment. When BIM is integrated holistically to the system, model will become the primary source of contractual and other building information instead of drawings. In addition, BIM tools adopted fabricators are able improve their own systems for example in a form of developing new drawing and layout generation layouts. [3]

Although offering the holistic approach, a fully detailed 3D model or other building model doesn't usually offer all the data needed for construction building. There are many technical specifications often missing from the model, such as material information, finishes, quality grades and construction procedures. Instead, documentation of the specification is still mainly executed by using traditional methods and form of documentation. [3]

2.2 BIM for Contractors

Utilizing BIM technology instead of traditional 2D based methods has a potential to save time and money of a contractor. Money and time can be saved through the improvement in the following factors:

- Clash detection and constructability analysis
- Quantity and cost estimating
- Construction planning and analysis
- Integration of schedule and cost control along with other management functions
- Fabrication taking place off-site
- Guidance, tracking and verification of activities during the construction
- Handover and commissioning. [3]

If BIM tools are used for estimating, coordination, construction planning, fabrication procurement and other functions, information needed for project management is available in earlier stage of the project. In order to enable aforementioned capabilities, ideally

a building model would contain the following types of information used by constructors or contractors:

- An accurate 3D model with graphic view of model objects whit capability to extract detailed building information as quantity and component property information.
- Temporary components, such as formwork, which are critical as project sequencing and planning point of view.
- Each building component to be purchased or constructed linked to text form specification, that is used for procurement, installation and commissioning.
- Analysis data based on project requirements and performance levels and used for procurement, fabrication and MEP detailing. Project requirements and performance levels are related to structural loads, connection reactions, heating and cooling loads and so on.
- Component specific design and construction status for tracking and validating the progress of components in design, procurement and installation phase. [3]

There is no single BIM tool for satisfying all the requirements presented in the aforementioned list. Instead, this list can be used for identifying information needed for a holistic BIM implementation. [3]

2.3 BIM for fabricators

2D CAD systems based design and coordination is error-prone, labor-intensive and requires long cycle times. Utilizing BIM technology will improve reduce cycle time for detailed design and products and eliminates nearly all errors in design coordination. It will also lower engineering and detailing costs, and improve preassembly and prefabrication. Furthermore, BIM technology will allow fabricators to accommodate late changes and improve availability of production and design information needed for life-cycle maintenance. [3]

BIM is mainly used for manufacturing engineered-to-order (ETO) components, such as the members of structural steel frames and facade panels. On the other hand, ETO component manufacturing can be implemented with computer numerically controlled machinery if BIM technology is used. These machines can, for example, take care of laser cutting and drilling for structural steel fabrication. [3]

2.4 BIM for owners and facility management

By using holistic BIM processes in the project, owners can achieve significant benefits by higher quality and better performing buildings. Owners can use a BIM model for:

- Increasing building performance by using BIM-based energy and lightning design and analysis for improving building performance

- Reducing financial risk by using the model for earlier and more reliable cost estimations and by improving collaboration of the project team
- Shorter project schedule: can be achieved by using models for coordinating and prefabricating design with reduced field labor time.
- Obtaining reliable and accurate cost estimates based on automatically generated quantity information in the model, which can be utilized even in the early stage of the project
- Ensuring program compliance. [3]

3 STUDIED SOFTWARE PACKAGES

This chapter will briefly introduce the main properties and common applications of Tekla Structures and Tekla BIMsight. Properties and applications are introduced in sub-chapters containing a task or a project phase in which they are most commonly used. The information provided in the sub-chapters is expanded and allocated in the chapter 9 based on the need of the BIM based packing system.

3.1 Tekla Structures

Tekla Strucures is a BIM software used for creating and management of detailed, constructible 3D structural models equipped with multi-material databases, such as steel, concrete and timber [1] [6]. It can be used for taking care of the entire building process from conceptual design to fabrication, erection and construction management (Figure 3.1). [6] Tekla is specially designed for the use of structural engineers, detailers and fabricators. [1]

The software can be used to interface with other applications, in other words related modeling and analysis softwares. It can also be used as a platform to develop customizable internal solutions. [6] Tekla Structures enables interactive modeling, structural analysis and design, as well as automatic drawing and report creation. The software also enables multiple users working at the same time. [1]

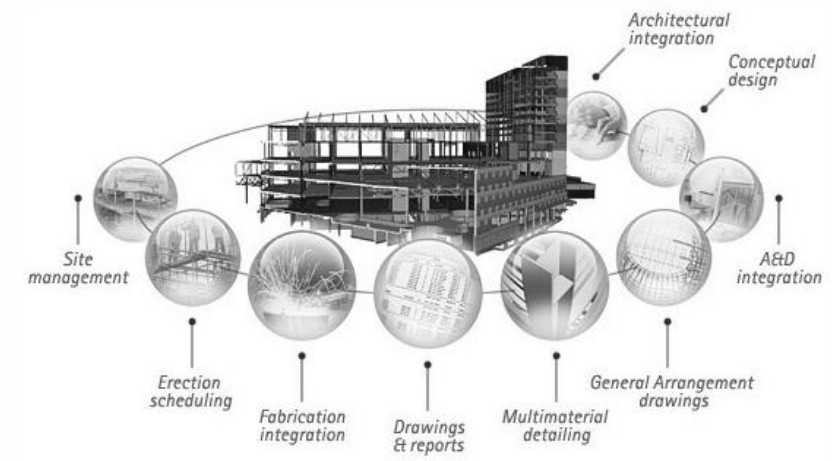


Figure 3.1 *Use of Tekla Structures in different phases of a project* [6].

3.1.1 Structural engineering

3.1.1.1 Getting started with the modeling process

Modeling process starts from defining model gridlines and floor elevations along with the x-y-z coordinates. In addition of defining the coordinates, objects are named and numbered according to company specified practice or according to general naming instructions. Naming the objects will create foundation to management of structural design and construction, i.e. management of drawings, reports and material and element fabrication. It is recommendable that the naming is taken care of in the early stage of the project. During the modeling process, every object, installation and cast unit will have a mark, which will contain prefix, position and other notable information, such as material type. Joints between the structural elements, such as beams and columns, are modeled after the modeling of structural elements. Besides structural elements, also joints can be chosen from the library containing most commonly used structures. [1]

Tekla Structures enables importing information from various sources including other models and 2D CAD based data. Export function can be used for bringing model information to other BIM application. Transfer of data between the softwares is enabled by using Industry Foundation Classes (IFC) file format. Other standards supported by Tekla Structures are CIS/2, DSTV, SDNF, DGN, DWG, IGES and STEP. [1]

3.1.1.2 Managing profiles

Profile catalog is a tool for managing information of profiles, their rules and types, and design and analysis properties of the profiles. Profiles are presented and grouped according to the determined rules in a hierarchical three. Using default settings, catalog displays standard and environment-specific profiles and generic parametric profiles. Profile catalog information is stored in the profdb.bin file. [1]

In the profile catalog, the profiles are grouped according to default rules in a hierarchical tree. You can also modify the rules to change the grouping system. Rules are read from top to bottom in the profile tree. Only the location of the rule in the profile tree matters, not the creation order of the rules. [1]

3.1.1.3 Managing materials

Material grades are found in the material catalog as a hierarchical tree. By default, standard and environment-specific materials are included in the material catalog. Material information is stored in the matdb.bin file. [1]

3.1.1.4 Custom components

Tekla Structures enables various tools used for defining connections, parts, seams and details, which are called custom components. Custom components are managed and modified in a custom component specific dialog box created by Tekla Structures. Custom component can be used similarly as any standard type of component. They can be modified using custom component editor. This enables creating intelligent custom com-

ponents which are automatically updated after the changes are implemented the model. Custom components can be created either by exploding and modifying an existing component or by creating them manually. You can also distribute created custom components using import and export functions. An example of a custom component is presented in Figure 3.2. [1]

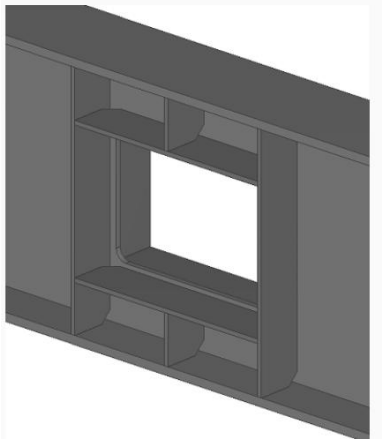


Figure 3.2 *An example of custom component* [1].

3.1.1.5 Structural analysis

There are three types of model concepts in Tekla Structures: physical model, load model and analysis model. Physical model is structural 3D model consisting parts created in Tekla Structures, and related information. Load model is consisting of load and load group related information allocated to the physical model parts. Created from physical model, analysis model is a structural model used for analyzing structural behavior and load bearing, and for design. [1]

For making structural analysis for structural design, Tekla Structures analysis model will be linked to analysis application enabling both import and export functions. The analysis application can be used for defining the forces, moments, and stresses of the structures. It can also be used for calculating displacements, deflections, rotation and warping of an object in different loading conditions. [1]

3.1.1.6 Clash detection

Clash Check Manager tool is for finding colliding parts, bolts or reference model objects. Clash Check management sessions will be include information of clash number, type, status and modification date, priority, object and assembly ID of two clashing items, and other clash identification related information, such as comment to a clash. According to the results of the check, clashes can be managed by either changing the status or priority of clashes. An example view of Clash Check Manager tool is shown in Figure 3.3. [1]

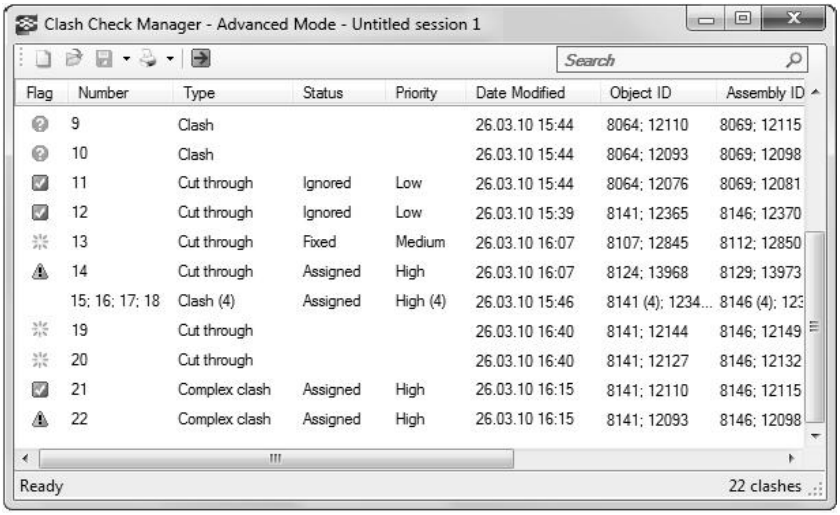


Figure 3.3 *View of Clash Check Manager tool* [1].

3.1.1.7 Creation and management of drawings

Tekla Structure drawings are created directly from the model being part of the model at the same time. Therefore they are automatically updated during the modeling and updating process and hence always up-to-date. Tool for the managing drawings is Master Drawing Catalog, which is based on generating drawings in one centralized location using master drawings. The tool also enables management of drawings in a form of revision control, locking, freezing and issuing drawings. The software includes many standard drawing layouts and functions which can be used for creating own layouts. It is also possible to export drawing, for instance, to 2D DWG or DXF file. [1]

3.1.1.8 Creating reports

Reports can be created based on modeling information. Using reports you can create, for instance, lists of drawings, bolts and parts. Similar to drawings, reports are created directly from the model and the information is always accurate. Source of a report can be either selected parts or entire model. There is large number of standard report templates. With Template Editor you can customize the existing templates. Also new report templates can be created from scratch. An example of a report created in Tekla Structures is presented in Figure 3.4. [1]

TEKLA STRUCTURES PARTS LIST FOR CONTRACT NO: 1 Page: 1
CONTRACT: Tekla Corporation Date: 16.09.2009

PartPos	Profile	No.	Material	Length	Area(m2)	Weight(kg)
Concrete	250*12000	2	K30-2	12000	227.6	0.0
Concrete	250*12000	6	K30-2	12000	250.2	0.0
Concrete	250*14997	18	K30-2	12000	278.4	0.0
Concrete	250*14997	54	K30-2	12000	301.0	0.0
Concrete	1500*1500	8	K30-2	500	7.5	0.0
Concrete	500*1000	4	K30-2	12000	37.0	0.0
Concrete	380*380	80	K40-1	4000	6.4	0.0
Concrete	4000*300	80	K30-2	12000	105.6	0.0
Concrete	CHS323.9X7.1	80	S275J0	4000	4.1	222.0
Concrete	800*400	80	Concret	8620	21.3	6620.2
P/1	IPE500	80	S235JR	12000	20.9	1092.7
P/2	IPE500	80	S235JR	13909	24.3	1266.6
	Total for 572 members:				38030.7	736117.6

Figure 3.4 *An example of report created in Tekla Structures* [1].

3.1.2 Construction management

3.1.2.1 Phase management

Phase Manager is a tool for breaking a model up into sections. In many cases, these phases are indicating erection sequences. With Phase Manager you can attach a phase number as attribute for model objects. [1]

Phase number can be used for creating reports and views, hiding objects and for copying objects from other models. This function is useful when having large project with many users working on simultaneously in as single-user mode. The process will start with creating a basic model that includes some basic objects related to the coordinates of the structure. The basic model can be copied to all users, so that they can work on a separate part of the building. After completing one part managed as a separate phase, it can be copied back to the basic model. [1]

3.1.2.2 Organizer

Organizer is a tool designed for management of model information and object property queries, and for classifying the objects. It is an effective tool for inspecting and managing all the model information in one place. Organizer includes categories for classifying and grouping model objects according to desired way. You can also view and report instantly properties of the selected objects. [1]

Two kinds of categories can be created in Organizer: Location categories and custom categories. Using location categories enables arranging model objects based on their location. Projects, sites, buildings, sections and floors are the types of the location categories. Custom categories can be defined based on your needs, based on object properties for instance. It is also possible to create automatic rules for the categories. This can be executed by using filters for keeping the categories up-to-date even after the changes are made in the model. [1]

Object Browser enables creating property templates for different purposes. Templates can, for example, be created for different object types and object groups, which can be grouped and sorted according to the needs. You can import property templates

within the model and from other Tekla Structures model. Property templates are in the .xml format. It is also possible to export a property table from Object Browser using the same file format. [1.1]

Organizer can be used in the multi-user mode. In this case, only one user can save the changes at a time. The first to open Organizer will become the main user and the only one who can save changes. Although only one user is able to save changes at a time, others can still select, create and modify categories and property templates. [1]

Properties can be tracked according to

- Properties (such as weight, content type or hierarchy level)
- Conditions (such as greater or equal, less of equal or equals)
- Value (numerical value or manufacturing type)
- Using and/or function. [1]

3.1.2.3 Lotting

Lots can be used for grouping assemblies for transporting them to site. Lotting means same as evaluating if the determined model parts with the number of units can be carried by a transfer vehicle or a container. Lotting information can be used, for example, for creating an erection schedule. [1]

Load-carrying capacity of the vehicle must be taken into account when defining lots. Therefore, weight of a lot must be under the maximum total capacity. Weight can be determined based on the model quantities and material weights. Lotting and Sequencer tools can be used together so that, for example, each part of the model can be loaded onto a specific container according to the erection sequence of the parts. [1]

In the lotting process you will first create boundaries for the lot, such as maximum weight, according to which Tekla Structures will create an empty lot with the defined properties. After creating the needed lots, desired parts must be selected and assigned to a lot. This process will continue until the total weight of the lot has reached the desired level. [1]

3.1.2.4 Sequencer

Sequncer tool is designed for naming sequences and defining incremental number to parts. Tool can be used, for instance, to create erection sequence based on the defined order to erect parts. It is possible to use several sequences for different purposes. You can also set a part to belong to several sequences simultaneously. To use Sequencer, you must assign a sequence number to a user-defined attribute of a part. [1]

3.1.2.5 Project Status Visualization

Project status visualization tool can be used to review the status of objects within a specific time frame. This tool is designed, for instance, for presenting different groups of parts in erection schedule with different colors. It can also be used for identifying the parts according to their scheduled fabrication time. [1]

Before project status visualization can be used, color and transparency settings based on the object groups including date rules must be determined. Project status visualization can also be based on tasks controlled by Task Manager tool. In this case, Task Manager is used to define tasks for parts and assemblies. [1]

Visualization settings can also be copied to another model by selecting the visualization settings in the model folder and copying it to the related folder with same name in the destination model. It is also possible to make the settings available in all models by copying visualization setting folder to the project or firm folder. [1]

3.1.2.6 Management of tasks and schedule

Task Manager tool is designed for contractors, sub-contractors and project managers. It can be used for adding time related data for Tekla Structures models for managing the schedule throughout the project. The tool enables creating, storing and managing schedule task and linking the task and the related object together. Based on the task management, it is possible to create customizable model views and overall 4D simulations of the progression of a project. [1]

Tasks can be created in Tekla Structures, or they can be imported from external project management tools, such as Microsoft Project. Tekla supports Gantt chart based scheduling with support for various chart symbol types. These model and schedule related symbols with the description are presented in Figure 3.5.

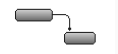
Symbol	Description
	Task that is not linked to any model object.
	Planned start and end dates.
	Actual start and end dates.
	Completeness of the task.
	Summary task. Summary tasks can contain other summary tasks as subtasks.
	Dependency between tasks.
	Milestone.
	Locked task. The task is marked as locked  in the task list.

Figure 3.5 *Chart types and functions of Tekla Supported Gantt chart* [1].

After creating tasks or importing tasks from other software they can be linked to the selected model objects. Subtasks, task type and contractors name can also be defined in the same tool. Furthermore, you can define the order of objects in a task. This can be implemented by defining and saving the order in which objects are stored in tasks. [1]

Production rate for tasks can also be added in Task Manager. This starts with defining a production rate for a task type, after which the task type is assigned to a task. Task progression can be tracked by setting the actual schedule and task completeness information. Additional information for a task can also be added in a form of web page links, related documents, project schedules and contracts. [1]

Task can be set to be dependant of another task or a milestone. Available types of dependencies are finish-to-start, start-to-start, finish-to-finish and start-to-finish. Dependencies are referred by using arrows in Gantt chart. Dependent task can be defined to move always when the preceding task is moved, or it can be defined that the task is only moved forward when the preceding task is moved forward. [1]

Color in the Gantt chart will indicate whether a task has been linked to the objects. In a case of blank chart task has not been linked to any model object. Both tasks and task types can be imported and exported between Tekla Structures and external project management software, such as Microsoft Project. [1]

Using Task manager tool, different task scenarios can be created, for example, in a form of design, fabrication and erection schedules. For easier project follow-up, separate weekly scenarios can also be created. [1]

Task schedules can be visualized in Project Status Visualization tool. Visualization starts with creating object groups in order to define which tasks are shown in the model. Object representation settings are then created to define how the task will be shown in the model. In the final stage the task schedule will be visualized by using the Project Status Visualization tool. Tool can be used for reviewing the status of modeling objects in a specific time frame. For example, erection schedule for a group of parts can be demonstrated with different colors. Tool can also be used for identifying the parts that are scheduled to be fabricated within a defined period of time. [1]

3.2 Tekla BIMsight

Tekla BIMsight is free software for project collaboration. It can be used for combining models of different project participants and for checking conflict both visually and by using conflict checking tools. It is also designed for communication within project parties in a form of notes, markups and project documentation [1]. The full version of the software can be used in PCs and in Windows 7 and 8 tablets. [7]

Software can be used for uniting modeling information from different design groups, for example Structural and MEP objects. Also markups can be added for the model view. You can, for instance, measure distance between objects and draw redlining on the model view. Tekla BIMsight enables validating the models by creating and

running conflict checks. After receiving the results of a conflict check nodes can be added in 3D view to ease to locate the conflicts. [8]

3.2.1 Managing projects

Software utilization starts with creating a project. It is usually based on the structural model created in Tekla Structures or other related software. You can add one model or model groups in one project. The supported file types of the software are
- IFC (.ifc, .ifcXML, ifcZIP)
- DWG (.dwg)
- DGN (.dgn)
- Web viewer files (.xml)
- SketchUp (.skp)
- STEP (.stp, .step)
- IGES (.igs, .iges) [8]

Transparency level of a model can be modified by using the slider at the bottom of the workspace. In addition of making the objects to have wireframe look, selected objects or entire models can also be hidden using ghosts button. Different objects and object groups can be set to have a certain color. This property can be used, for example, for easing the recognition of certain group of objects. [8]

3.2.2 Navigation

Tekla BIMsight includes all the common navigation modes, which are
- Rotate around point mode
- Pan mode (move around in the model view)
- Walk around mode (especially useful when walked inside a virtual building)
- Look around mode (rotate in one position)
- Full-screen mode (view the models in the full-screen)
- Navigation Circle
- Zoom slider (for zooming in and out in the model view) [8]

Aforementioned navigation modes are presented in Figure 3.6.

Figure 3.6 *Navigation modes available in Tekla BIMsight* [8].

3.2.3 Saved views

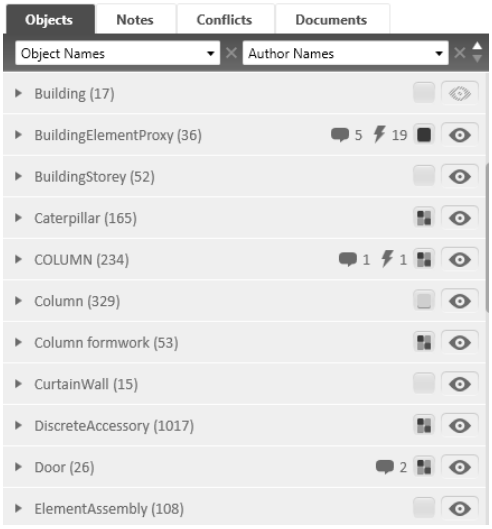
The software enables saving views for a later use and for showing important details. It is also possible to arrange saved views in view groups, and these saved views can be watched thorough a slide show. Saved views can be arranged to suit the needs by dragging them at the bottom of the workspace in so called view strip. [8]

3.2.4 Managing objects

Object browser is designed to present all the objects belonging to the project models. It enables grouping and sorting the objects according to their attributes. Following information can be found in object browser:

- Name of the object
- Number of documents linked to the object
- Number of notes linked to the object
- Number of conflicts associated with the objects
- Attribute of the object (for example, object material, shown attribute depends on object grouping and sorting settings)
- Color symbol
- Visibility symbol. [8]

An example of the view in object browser is illustrated in Figure 3.7.



Figures 3.7 *An example of the view in object browser.*

3.2.5 Markups

There are two types of markups in Tekla BIMsight, dimension lines and markers. It is possible to measure distance between points, lines and surfaces. In the case of reinforcement bars, you can measure distance from end points and center lines of the bars. [8]

Marker, as well as redlining can be drawn in the model view to highlight significant details on the model. Redlines with related views can be linked to notes. Besides mouse of the computer or other conventional tools, also SMART boards can be used for drawing in the model view which is an effective property in site use. [8]

3.2.6 Conflict checking

Conflict checking starts with creating a conflict rule. This can be made by choosing two object sets, usually two separate models. You can also choose an overlap tolerance to be tolerated or a minimum distance between two objects in the conflict checking. [1.8]

Using conflict browser, you can examine all the conflicts that have been found in conflict check. Conflicts can be grouped, sorted and tagged. In addition, you can mark conflicts with different colors in order to represent various statuses. Conflicts can be both grouped and sorted by using conflict rules, object names, tags or status. Grouping by tag enables you to track the most critical conflicts. Using grouping by status you can, for example, find all new or critical conflicts. An example of the view in conflict browser is presented in Figure 3.8. [8]

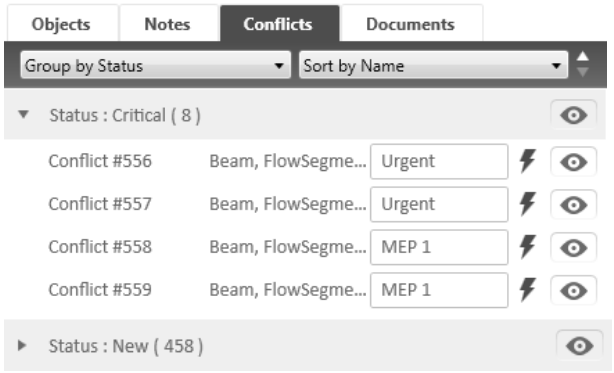


Figure 3.8 *An example of the view in conflict browser [8].*

3.2.7 Notes

Notes can be added to the selected objects and model view. They are useful for attracting attention on specific details in the model. All the notes of the project created in the model or imported from outside application are displayed in note browser. Notes can be grouped and sorted by type, tag, author, creation date, date of the last update, read/unread status, or public/private status. An example of the view in note browser is illustrated in Figure 3.9. [8]

Notes can be shared with other project members by using two methods: You can share notes by using shared project as a project folder. You can also share notes by distributing note files. When using shared project, adding a new public note will be automatically updated to the note browser for all project members. If needed, you can add private notes for your own needs. By creating note files, you can share notes with other members or receive their notes by using e-mail. The shared notes are in BCF format

(.bcfzip) and they can be read with Tekla BIMsight or other softwares supporting BCF format. [8]

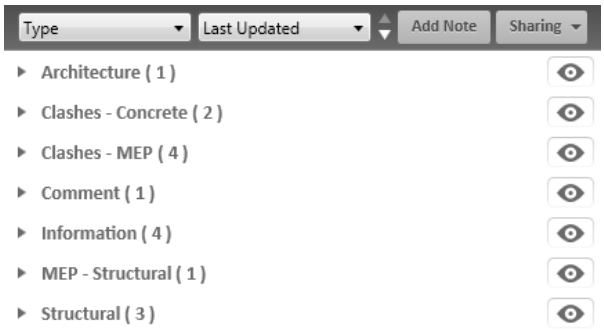


Figure 3.9 *An example of the view in note browser [8].*

3.2.8 Attaching documents to the model

Documents can be added to model by using the document browser. An example of the view in document browser is shown in Figure 3.10. The browser displays all the added documents and you can group, sort and tag the documents. You can sort the documents according to the name, author, file type, age or tag type. Documents can also be linked to objects by choosing the document and selecting the objects and pressing "link to selected". [8]

Figure 3.10 *An example of the view in document browser.*

3.2.9 Tekla BIMsight Note: software for on-site and on-the-move communication

Tekla BIMsight Note is a tool for on-site communication and it is free of charge. Notes can be sent, received and replied in Tekla BIMsight Note using mobile device. The software is compatible with iOS and Android mobile devices, whereas full version of Tekla BIMsight can be used in Windows mobile devices. [7]

Software can also be used during the design coordination process as a complement for the work implemented in full version of Tekla BIMsight. Important issues, such as clashes, design issues and RFIs (requests for information) can be delivered from Tekla BIMsight to users of Tekla BIMsight Note. The major advantage is that all the stakeholders that are part of the construction workflow can combine the modeling information in the same 3D environment. [7]

4 CONDUCT OF THE RESEACH

The research is based on finding out and evaluating different BIM based tools and software properties that are helping to improve the speed of element erection by improving the current packing system. Therefore it is a qualitative research as its nature.

At the start of the thesis, there was a brief introduction of the current situation of BIM implemented as a literature review. It was focusing on BIM related construction management and also contained a description of the current situation and trend of BIM based logistics. Furthermore, the section was introducing the use and general properties of studied sortwares, Tekla Structures and Tekla BIMisight, with construction management in focus. The chapter was designed for the use of the company and other readers for providing basic knowledge of the nature of BIM.

Empiric section will be based on interviews and studying of the properties of the softwares. Data presented in Tekla BIMsight is created using the case Tekla Structures model. Software properties are studied focusing on the properties that are enhancing management of frame installation logistics at the site. Furthermore, properties of both Tekla Structures and Tekla BIMsight are studied in order to meet their collaboration properties.

Also other BIM softwares could have been studied in the research. The engineering company involved in Wärtsilä's projects is using Navisworks Manage for coordination of structural, mechanical and electrical models. In addition, the project team and the site team provided by Wärtsilä is using Navisworks Freedom for checking model 3D view in the case clashes and other installation related issues.

The reason for not making a research of frame installation and packing related properties of Navisworks Manage is that it is especially designed for uniting information found in several models. Since Tekla Structures is the source of structural modelling information it is a practical choice for a modelling software to be utilized for BIM based packing management. In this research, Tekla BIMsight has been chosen to be the software for collaboration and site management due to its interoperability with Tekla Structures. It is also expressing more detailed structural data, such as assembly numbers and part numbers of the structural parts, compared to the other free software designed for site management, Navisworks Freedom.

4.1 Interviews

Interviews were implemented through phone, Wärtsilä's internal video conferencing software and face-to-face. Also filled out forms send through e-mail were used. Only

aggregation of all interviews is published in this thesis. Interviewee specified answers are not presented in this thesis but delivered to Wärtsilä as a separate document.

Most of the interviews were implemented in one stage. Interview allocated to the Structural Designer was completed using additional form after studying software properties was finished off. Interviews took between 60 and 90 minutes. They were recorded in order to ease writing down the answers. Questions were consisting of main questions and expanding questions defining the topics of the main questions. Main questions of the interview forms presented for the interviewees are introduced in subchapters 4.1.1 - 4.1.4.

Interviews were clarifying current systems and possibilities enabled by the systems. Also the needs of the stakeholders were located. The interviews were allocated to two Site Supervisors, two Section Managers, three Chief Project Engineers at the office, one Structural Designer and the main frame element supplier. Only the stakeholders of Wärtsilä's projects were interviewed since the research is a company specific case study.

4.1.1 Main frame element supplier

The main frame element supplier provided information of the current element manufacturing and packing system. It was defining the structure of the company and which departments within the company are dealing with implementing frame element manufacturing and packing. This means finding out which work phases workshop manufacturing and packing is consisting of and by which department. Furthermore, it was studied which kind of documents the main element supplier is using in order to carry out element manufacturing and packing.

Supplier was also clarifying their capabilities for implementing pre-determined packing system. It was found out which kind of documents and in which form do they need for fulfilling the requirements. It was also asked if they were able to use building information models without converting the data to 2D documents. In addition, the supplier was reporting if and how they had fulfilled predetermined packing order before by the request of Wärtsilä. The supplier also informed if they had used barcode system for logistics between the supplier and the client by the request of the client.

4.1.2 Site Supervisors and Section Managers

Site Supervisors and Section Manager were clarifying current packing and unpacking protocols. It was asked how and in which order frame elements are usually found to be packed within containers. Furthermore, it was examined how the elements are grouped after unpacking and which kind of documents and element marking system are utilized for implementing element unpacking and grouping. Also possible utilization of 3D models and the way of utilize these models at sites was asked from the interviewees.

Types of storage areas for the elements were identified in the interviews. One thing to be find out was how containers are brought at the site and how they are groped in the

laydown area. It was also asked if frame elements are sometimes put back in the containers and in which situation.

It was examined which stakeholders at a site are typically taking care of certain logistical issues. Furthermore, it was asked if the interviewees have been involved in projects with set requirements for packing order. Biggest problems in current packing related protocols were also localized.

Site Supervisors and Section Manager were also clarifying current protocols in installation logistics. It was asked which kind of organization is taking care of supervising installation works and how. Documents used for managing installation works were also identified. It was also studied whether these documents are used in digital or paper form and if company's internal project bank is used at sites. Interviewees also told if they are using 3D models and tablets in their work and if they see them beneficial.

Interviewees were explaining typical installation order that they are using for engine hall frame. Furthermore, interviewees were clarifying the method and initial data that they are utilizing to select this frame installation order. They were also expressing their main reasons to choose their installation order.

Needs for improving current packing system as site point of view were also studied. It was asked if current element marking system both in documents and physical elements is sufficient to carry out element unpacking efficiently. In addition, strengths of the current system were studied. Site Supervisors and Section Managers were also telling their opinion of functionality of the current installation protocols, in other word which are the factors that could be improved and how.

4.1.3 Chief Project Engineers

Aforementioned questions asked from Site Supervisors and Sections were also allocated to Chief Project Engineers. Furthermore, it was asked which kind of conversations related to frame element packing order are usually underwent in a project. It was found out how and in which documents the agreed packing order is expressed.

It was also asked how the interviewees have usually divided an engine hall for manageable areas such as phases, floors and sections. In addition, benefits achieved by using the division were identified. It was asked if there is some systemized way or standard to pack frame element by the supplier. Content of this standard was also described.

It was asked from Chief Project Engineers how predetermined installation sequence is pointed out in a project. This means describing related documents and for which purposes the sequence is used. It was also clarified how Project Engineers and Site Supervisors are interacting between each other. Furthermore, protocols against missing parts in the delivery or manufacturing mistakes were described.

Chief Project Engineers were telling main issues related frame element delivery. Also the latest improvements in frame element packing are localized. It was also found out whether predetermined packing order is causing extra costs. In addition, it was asked whether the interviewees are seeing installation sequence number based assembly division as a reasonable way to manage frame installation.

4.1.4 Structural Designer

Structural Designer that was interviewed is working at the company taking care of engineering in Wärtsilä's projects. He was interviewed for clarifying engineering company's current modelling procedures and readiness to fulfil the changes in the modelling process required by the predetermined packing system. Needs to improve current systems were found out in the interviews of the Site Supervisors and the Project Engineers.

Structural Designer was informing software versions of Tekla Structures that are used in the engineering company. He was also telling company's plans of taking the latest Tekla Structures version into use.

Structure of a typical structural design team and each participant's job description was identified in the interview. Furthermore, it was asked in which point of time of a project does the modelling work start and what is the content of the model in this phase. It was also asked which level of modelling information taken from old projects is used in a new project and which data is defined project specifically. In addition, modelling libraries and other modelling standards of the engineering company were identified in the interview.

Interview was also introducing modelling co-operation protocols between Structural Designers and MEP designers. It was asked in which file format modelling data is exported and in which collaboration software it is used. Content and accuracy of typical export data was also identified.

It was especially clarified how modelling information could be utilized for managing quantities and frame delivery. Model sharing system between Tekla Structures users in the engineering company was identified in the interview. It was also asked if the company has a standardized phase, section or floor division for an engine hall frame and if volumetric objects are used for managing assembly groups. In addition, it was asked if the interviewee has been involved in projects with detailed assembly division and how this division was implemented and managed.

One think that was found out was whether the engineering company is using Model Organizer, predecessor of the Organizer tool studied in this thesis. In addition, it was asked if the company has plans for taking the Organizer tool into use. Interview also clarified the way modelling information is used and filtered in order to create 2D documents. Content of assembly lists and steps for creating them were especially introduced in the interview. Procedures for managing document templates were also reported.

Furthermore, co-operation between the frame element supplier and the engineering company was identified in the interview. It was asked if the engineering company sometimes sends whole model for supplier's use. It was also asked which documents are delivered for the supplier and in which stage of a project. In addition, other procedures of communication between Structural Designers and the supplier were identified.

4.2 BIM based communication and simulation tools

At the moment BIM is mainly used for generation of drawings and list in the employer company. In this thesis it is studied how to implement BIM based communication between Structural Designers and Project Engineers, and Project Engineers and Site Supervisors. Both design and frame installation phase are considered in planning BIM based communication system. Content of this system is based on the information provided by the interviews and general protocols in construction.

Properties of communication tools are studied with special focus on managing frame installation and element packing. On the other hand, it is examined how to utilize these tools for managing communication during the whole project. Compatibility between presented tools and current systems of Watseka is also studied. Communication tools with feasible protocols are presented in the chapter 7.

Simulation tools are introduced for finding ways to improve frame installation management. Tools included in Tekla Structures and Tekla BIMsight are both introduced in order to find the most practical one. It is also studied how to deliver simulation data between project stakeholders using the presented communication tools. Simulation tools are introduced in the chapter 8.

4.3 Managing frame element packing and installation using BIM

Studying the properties Tekla Structures and Tekla BIMsight is implemented as a case study. Structural model used for software testing is including engine hall frame of an existing project. Softwares are tested in order to find out their limitations and whether they are well-matched on the procedures and the goals of Wärtsilä.

Basis for software testing is determined by the interview of the main frame element supplier. The supplier is telling which kind of data it can utilize for managing predetermined packing order. Based on this information, most practical tools and ways to produce the required data is searched in Tekla Structures.

Managing both frame element packing and installation works are sought through dividing the engine hall model for manageable areas. Since deliveries are managed using modules, it is practical to use the same division in frame element categorization. It is also studied how to divide one engine hall module to several phases, sections and floors if this sort of division is needed in the project.

Most of the modelling categorization has chosen to be done using the Organizer tool. Reason for this is that it seems to be the most diverse tool in Tekla Structures 20.0 and a practical tool for creating and managing model categorization data. For the same

reason it seems like it could be used for managing lotting information and planning installation sequence grouping of frame elements.

Modelling procedures needed for determining installation sequence related packing order is presented in chapter 9. Frame element type and location specific installation sequence grouping with arguments for the chosen grouping is also presented in the same chapter.

In addition to better packing management, frame installation management is sought through BIM based installation management at the site. First it is studied how to export required modeling data created in Tekla Structures to Tekla BIMsight. Then it is found out how to utilize this data for frame installation and element unpacking management using Tekla BIMsight. Needs are presented in the interviews of Site Supervisors, Site Managers and Chief Project Engineers. It is also studied if it is possible to replace assembly drawings in frame installation management using Tekla BIMsight.

4.4 Proposal for improved project management system

Result of the finding will be summarized as a proposal of improved project management system. Sketch of the content of BIM based packing system with related installation logistics and project management system is created based on the literature review, interviews and tested software properties. Information provided by interviews is determining which factors of current protocols need to be developed. They are also describing current system which is necessary to know in order to make old and suggested new protocols compatible to each other.

The proposal is formulated in such way that it is easy as possible to implement in practise. It also has to be described the system in dense and brief form clearly pointing out suggested new protocols with related old protocols. The system is portrayed using both text and figures.

4.5 Discussion and conclusion

Feasibility and significance of the system and related findings is evaluated in “Discussion and Conclusion” chapter. It is assessed whether the objectives of the research are corresponded. Deviation from the expected results along with reliability of the research are also presented in this chapter. Furthermore, limitations of the system are introduced in order to evaluate feasibility of the findings. Suggestion of follow-up researches are presented at the end of the chapter.

5 CURRENT SYSTEMS AND PROTOCOLS IN INSTALLATION LOGISTICS AND MODELING

5.1 Main frame element supplier

5.1.1 Manufacturing order and procedures

Frame element manufacturing process starts with opening the order by Sales Department. After receiving the workshop documentation, such as manufacturing drawings and lists, they are analyzed to find out technical and production possibilities of manufacturing. Aforementioned stage and developing optimal cuttings of the material are executed by Technological Department. Next the Purchasing Department will order the materials for construction steel, fasteners and gratings. After this the Technological Department will check 3D model as a dstv file format for individual details.

Production will take care of both element and detail manufacturing as well as corrosion protection of the elements. Supervision Department is responsible for quality control and general welding. Logistic Department will take care of the element packing in the containers. Manufacturing sequence is not determined by the type of items. Instead, all the manufacturing production is based on the planned schedule of shipments.

Manufacturing is executed according to manufacturing drawings and lists based on the Tekla Structures model. Lists consist of Assembly list, Part List, Assembly part list and LxWxH list (list based on element or part dimensions). In addition, dstv files exported in Tekla Structures are used for checking details and element compatibility. MASP list are used for managing and separating different building entities.

5.1.2 Current packing system

After the welding has been implemented elements are moved to the painting area where elements are painted and grouped as packages. If the welding or painting shop are temporary booked, elements are stored on a special area. Painted elements are moved to the storage area. When all the elements needed for a specific building, for example for the engine hall, are ready the supplier will start to pack them into containers.

Elements are packed according to the building division presented in the project specific MASP list. Packages are formed based on the components with similar type of structure, such as columns. Elements are packed into containers aiming at the maximum 20 000 kg payload of one container – in practice this means 14 to 18 tons of steel.

5.2 Current packing logistics as constructor and site point of view

5.2.1 Site Supervisors and Section Managers

Frame elements are mainly shipped in open containers. Since it is relatively easy to unpack the open top containers and the risk of damaging the paint of the elements is smaller than in the sealed containers. The supplier is tightening the content of the container by using wooden support and filling materials.

Elements are wedged in order to prevent element movement during the transport. Furthermore, the supplier uses carton protection pads between the elements to prevent them to damage each other during the transport. On the other hand, as a result of the packing marking labels for the elements or packages are sometimes gone off and therefore parts are hard to find.

Elements can be unpacked from the top side of the container by using hoist. Telehandler is also a useful tool for managing element unloading. If regular containers with doors are being used, it can be more difficult task to unpack a container.

The supplier has sophisticated tool to pack the containers efficiently. Instead, it is common that the site doesn't have same kind of equipment to unpack the containers effectively and it takes lots of time to get all the elements out of the containers. Fasteners can be broken and parts can be damaged if the lifting capacity of a telehandler is not sufficient when the goods packed on the pulling rails are being moved. This problem can be solved by keeping the packing units lightweight enough.

In many cases there is an intermediate landing area for the containers arriving from the harbor near the site. Containers can then be quickly relocated to the laydown area once they are needed. Sometimes containers can be stored to the intermediate landing area located in the harbor and in some cases in the rented area near the site.

Many times the crane capacity both in the harbor and in the site is very limited and the road transport utilization rate maximized. In this case containers are brought to the site at a random order. The containers are usually placed side by side to each other in the construction site. They are not usually grouped according to the content of the container when brought to the site. However, grouping can be used after all the containers are brought to the site if the project is especially large and the laydown area is sufficient, which is not usually the case. Laying the containers in the laydown area is planned and expressed as a laydown drawing so that all the containers are fitted in the area. Open top containers must be placed on top of the normal sealed containers if the containers are stored to more than one layer. There can be no other container on top of these open containers.

Element tracking is based on finding the assembly number written as a metal tag on an element surface. Once all the building specific elements are unpacked they can be tracked by checking the metal tag. Element marking system to be used is defined in the contract between Wärtsilä and the frame element supplier. Only assembly numbers are used for tracking the elements after they have been unloaded.

One of the biggest problems in the current packing system is that there is usually no systemized packing order of elements. Containers are also filled randomly in order to get as close as possible to their maximum payload capacity. Even bolts, plates or other small parts can be packed randomly in the containers. It's not uncommon that the elements belonging to different buildings are mixed together.

In order to find elements you have to unpack all the containers and much additional time is required for element search and removal. Elements must be moved from one place to another many times when you have many elements needed in the final stages of installation moved or put on the laydown area.

For this you need a big laydown area. Constant element removal will most probably harm surface treatment of the elements, which means double work when patching of element surface is required.

Some Site Supervisors stated that similar elements, such as columns, trusses and beams are sometimes grouped and packed in separate containers. Still, small elements can be found on top, bottom, back or front corner of the container.

Assumption is that the heaviest and largest elements are located at the bottom of a container and lighter ones on top of the larger elements. Columns are needed in the first stage installation, but they are usually packed at the bottom of containers. The start of unpacking, in other words gathering the columns is also the most time consuming phase of the work. All the other elements on top of the columns must first be unpacked from the container. These items, such as railings, are usually light weight and not installed at first stage. Gathering the columns for first stage installation of the engine hall usually requires up to ten containers to be unpacked.

Elements that are not needed in certain stage of the installation are almost never put back in the container. The main reason is that it is not practical to track single elements, take them out of the container and fill the container again. Other reason is that the contractors usually refuse to do extra work since they have only bidden for element unloading and for the installation work based on Bill of Quantities. Instead, all the elements are grouped and gathered according to their assembly mark.

There are also single projects with set requirements for pre-determined packing order. Other Site Supervisors has been involved in the project that the frame elements were packed according to erection sequence since there was not much free space for unpacking the containers on the site. Also small items, such as bolts and plates, were packed in the same containers with related structural elements. Small buildings especially were installed as the elements were unpacked and it was possible to install the elements straight from the container. This saved much installation time compared to equivalent situation without organized packing order.

Packing list are kept in a excel form in the site and printed if needed for controlling the unpacking. Packing lists contain the information of the building the element are belonging to and the element assembly numbers. These lists are handed over to the contractors according to which they will track the elements. Packing lists, assembly lists and 2D assembly drawings are utilize for finding out which elements or parts are needed

next and for planning the installation sequence. Also 3D steel structure assembly drawings and 3D Navisworks model are used in some cases. Part numbers are used if modifications must be done in the case of element factory defect or faulty design

The unpacking of the containers according to the packing lists is being taken care of by the contractors or separate persons specialized for taking care of the logistics. Also Site Supervisors are used for managing the unpacking. Either Wärtsilä's Site Managers or the Site Supervisors of the contractors will tell the persons specified for managing the logistics which elements are needed next, according to which the right containers are being tracked. Supervisors and Site Managers will also advice the persons taking care of the logistics if some of the elements are missing or if some other issue occurs.

The procedure of unpacking the containers differs depending on the project, the organization of the contractor and the available space on the site. In an ideal case, all the major elements are spread out and grouped in the laydown area. Frame elements are restored or group on the laydown area using wooden structures beneath and between the elements. These element groups are then relocated in the installation area or other storage area using a truck when related installation stage is taking place. They are relocated using fabric ropes but can be battered when hitting to other items or on the ground. Many times as many as three different elevators, trucks or cranes are used for overall element relocating.

On the other hand, it is not a necessity to always group all the elements before the installation can be implemented. You can also take small number of parts in to the site and install them and then find the rest of the similar parts. In some cases the containers are emptied depending on the need of the day. Sometimes it is best to position a container close to the working area.

The unpacking is planned according to the current installation phase based on the main time schedule. Detailed schedule and related element unloading sequence are based on Site Supervisor’s experience and personal view. The schedule is usually really tight, so the installation and the unpacking sequence are planned so that both structural and mechanical works can be implemented incessantly as possible.

5.2.2 Chief Project Engineers

One of the most commonly underwent conversation between Wärtsilä and frame element supplier is related to building based frame element packing order. It is being discussed which element are packed together and whether it is possible pack the element according to the gridlines. It is also ensured that elements belonging to different buildings are not mixed together if not especially planned to do so. This can be ensured, for instance by making the assembly lists building specific.

Issues related to the frame element packing vary highly on the project size and type. If the project is small in size it is sufficient to survey that the delivery and the packing are accordant the MASP list. In other words, requirements set for the packing can be loose if the project is small and simple enough, for example, as a scheduling point of view. The whole SAP based procurement for the project is based on the division pre-

sented in MASP list. Besides SAP procurement same division is also used in assembly lists delivered to the supplier. Supplier is packing the containers according to the information found in the assembly lists.

In large-size and challenging projects the schedule is usually tight and the size of the frame element delivery large. In this case scheduling of design phase, shipment and installation works is really time-consuming but the total time reserved for the project can be short. The power plant must be designed and the related elements be delivered on the site in split phases.

Even if the schedule was loose or the site laydown area large enough it is beneficial to split the power plant and delivery in multiple phases for better delivery management. Furthermore, there is always less work needed by the site team if the elements have been packed according to element type or installation sequence in general. In the case of MASP list division also the structural design can be divided to phases in order to manage the deliveries. For example, stacks and both of the two engine hall frame structures can be set to be their own delivery. As in case of a small project, MASP list is presenting this division of delivery.

It is a good practice to send all the manufacturing drawings belonging to one engine hall module for the supplier at the same time. On the other hand, frame design and manufacturing can be interlaced and time can be saved if the manufacturing drawings are sent in multiple phases. The downside in using this system is that these already manufactured elements must be modified if there will be, for example, major growth in the structural load of upper layer structures.

On the other hand, the site team might want to change the planned erection order. In this case the delivery must be flexible enough and collaboration between the project and the site team good enough to correspond on the changed requirements.

There is a standard between Wärtsilä and frame element supplier according to which the supplier will pack the elements. The detailed, frame installation sequence based packing order instead is not part of the standard and the project team must set the requirements project specifically. It is agreed between Wärtsilä and the frame element supplier which elements can be packed in the same container. Usually the frame elements are packed building specifically.

It is also agreed which elements can be used if the aimed 20 000 kilograms weight of a container is not achieved using the elements belonging to one of the required element packing groups. The main principle is that packages of the main element are used packed in a container and then rest of the remaining space and weight is filled with secondary parts. In practice this means that heavy elements are packed at the bottom of a container and lighter parts on top of the heavy elements. Bolts and other small installation parts are usually packed in the same container. These parts are stored in the storehouse container from which the construction workers can pick the parts when needed.

The current protocol by the supplier is to pack similar size and similar type of frame elements belonging to the same building in a same container. Same kinds of elements are grouped in packages inside the container. One of the interviewees has visited the

workshop of the frame element supplier. Based on his observation, frame elements are also manufactured according to element size and stored in the intermediate landing area. The supplier is basically manufacturing the elements in the order equal to the order of the related assembly list. On the other hand, elements consisting of different kind of profiles are manufactured in different production lines.

One of the interviewees is usually making his own preliminary frame installation sequence plan for the project. The plan is then used for managing the structural design process, especially the production of manufacturing drawings. This interviewee has usually set the packing requirements for the supplier throughout the phone conversation. One presented option for affecting on the manufacturing and packing order could also be to deliver manufacturing drawings for the supplier in separate packages based on the installation sequence division. This would disable the supplier to pack the elements any other way that the required one.

Frame elements are usually packed in open top containers because it is easier to unpack the elements. Some large size elements, such as columns belonging to the engine hall with big size engines, must be shipped outside the container since they are not fitting in a container. When the containers are being opened and unpacked at the site, all the elements must be dragged out of the container and grouped according to the element type. Elements can be grouped in the laydown area or on top of the engine hall foundation if it has already been casted or if there is enough time to do so.

On the other hand, if the packing order doesn't match the installation order, many of the elements are unpacked too early and stored on the laydown area. It also takes lots of times to unpack the element if the unloading vehicles are not particularly suitable for the use. This will most probably harm the elements and touch up paint is needed. Patch painting is time-consuming and many times it is implemented after all the frame elements have been installed.

Many times there is a separate person taking care of logistical issues at the site. Logistics Engineers are usually used if the site is challenging and large enough. Otherwise the Site Engineer is taking care of the material inspection along with the schedule inspection.

5.3 Current installation logistics

5.3.1 Site Supervisors and Section Managers

The type of the site supervision organization depends on the project type and size. Many times the person responsible for controlling the unpacking and the element installation is Civil Site Supervisor or Section Manager. In addition, there can be a person taking care of the logistics so that the right containers are delivered to the site on time. Sometimes there is a separate Building Supervisor for managing the structural installation works. Building Supervisor and a person taking care of logistics are also assisting in managing searching and unpacking of the containers.

Most of the actual supervision work is implemented by the supervision of the work of the contractor. Site Supervisor provided by Wärtsilä is responsible for controlling container unloading and the installation works as well as documenting the progress of the work. He is concretely ensuring that the quality and progress of the work equates the plans.

2D drawings and different kind of lists are mainly used for finding out which elements or items are needed for the installation. Also 3D assembly drawings, such as column erection related 3D assembly drawings, are used. One of the interviewees is using position numbers added form from 2D drawings to 3D view drawing for easing the erection sequence planning. In general, 3D drawing is one of the most important types of drawings. It can be used for understanding the outline of the whole structure needed for managing and leading the installation works implemented by subcontractors.

Some of the interviewees are using drawings in a digital form and is looking for them via project bank. Some details are also required to be checked in the drawings of mechanical or electrical engineering. Needed drawings are then printed on the paper form. Still, main principle is that the project bank should not be used by the site since the site team is not taking part of the conversations and decisions between the design and project management teams in the office. The right procedure is that the project management team works as a middleman between the project bank information and the site team.

One of the interviewees is using following system for managing frame installation: Contractor is delivering on weekly bases the list of the elements that have been installed. Using excel form assembly list it is possible to make the progress S-curve what it comes to the both weight and the number of elements that has been installed. This curve will indicate in rough level the progress of the element installation.

Normally the progress per weight gives a little bit twisted interpretation of the progress: In the beginning of the installation works you will see very high speed progress when installing the columns. Installation of wind taking bracing and support beams instead is more time-consuming when measured in kilos. On the other hand, it is still useful to color drawings on the wall of the site office as the parts have been installed.

Installation sequence of the building is determined by the experience of the project stakeholders, structural requirements, schedule, site conditions, material availability and input from other disciplines than site supervisors. Structural integrity must be assured throughout the whole project. Material availability also affects to the installation sequence. It is possible that the materials for certain buildings or certain parts of the buildings are delivered later, so installation sequence must consider this aspect. In the detailed level, it is determined based on which other works has been completed and what work can be started. Also the capability of the contractor and other stakeholders affects to the realization of the planned installation sequence. Mechanical, electrical, commissioning and HCAC team has their own requirements for schedule trough starting and finishing their work.

The erection sequence in the detailed level is based in the personal experience and opinion of the person in charge of the frame installation. The frame system of the engine hall is quite simple as a structural point of view. For the same reason installation sequence can be chosen multiple ways.

The erection order is usually based on the location of the bracings and stiffening of the structure is taken care of at the early stage of the erection works. This order will ensure right crosswise measure values. The current trend is to describe the installation order of bracings more specifically in the installation instructions.

Sometimes the installation sequence in a gridline level is expressed in the assembly drawings or in the list of drawings. Still erection sequence or installation direction is not introduced in the assembly drawings or any written instruction by standard. Sometimes there are some set requirements in a rough level determined by the project management or the site team. In this case, the requirements are described as a result of a meeting rather than in a detailed and separate document.

After the frame elements are grouped by the element type, frame installation can be started from start, end or middle section of the building. Only requirement is that the installation must be started from the gridline stretch containing the bracings. A good way to install the frame elements is to start from one end of the engine hall, so that all the frame elements are installed from bottom to truss structures gridline by gridline. This option is also used when the span of the crane or the free space for placing the crane in the site is limited. Other good option is to first install all the lower level columns, bracings and support beams, after which the trusses and the related bracings are installed starting from one end of the engine hall.

Employees dealing with the mechanical and electrical installations are usually starting their works at specific area of the building once it is possible, in other words once all the elements needed before their work can be started has been installed. Therefore all the main elements at the specific elevation are tried to be installed before the specific installation area is delivered for the use of mechanical or electrical installation works. As a result, it is a good practice to install all the main inside frame elements in the same phase with the rest of the same elevation frame structures.

The level based installation sequence is the following: columns, bracings, support beams and trusses. Columns and related bracings are installed fist for the whole building or for multiple gridline sections. Then trusses are installed on top of the columns, then bracings and tying beams, after which all the secondary beams and supports, and so on. One benefit of the aforementioned gridline based installation sequence is that the wall panels can be installed at the early stage of installation if needed. The installation practice of the radiator structures is quite similar regardless the project: Radiator structures are installed rather straightforwardly from bottom to top layer elements.

Trusses are usually assembled on ground level. One of the interviewees favors assembles before lifting the parts in place as much as possible. Reason for this is that before a lifting the touch up for paint damages should be done and members should be cleaned. Also torquing of smaller attached elements can be done. Doing all this later is

always more difficult since access later on is limited. Checking possible paint damages and deficiency in the torquing is also more difficult and double expensive work is required when implementing all the assemblies after the lifting.

Generally speaking, the presented installation sequences are very beneficial if the schedule is tight and many work phases are taking place simultaneously. It is common that there is another building or some other block that prevents placing the crane and choosing freely the installation sequence. In this case the installation works must be started from the certain part of the building. There can also be two or more buildings with shared critical path to be installed at the same time. On the other hand, the building can be small enough for freely choosing the installation sequence.

Aligning the columns is the most time consuming phase of the frame element installation. If the aligning is done properly it is easy and quick to install the bracings and the support beams. Proper aligning of the columns is also important as a technical point of view. If it is not done properly, installation of other parts will be much harder.

The distance between the container area and the installation area can be long. In this case, elements are first unpacked from the containers in the trucks using a hoist. Sometimes the laydown area and the element installation area are near each other and the elements can be moved to the installation area right from the containers using the crane. This system is used when there is only little free space in the laydown area and only a couple of containers can be unpacked at the same time.

In case the laydown area is big enough, elements can be unpacked and grouped on the laydown area. Usually all the columns, bracings and beams are grouped on the engine hall foundation or near it before the frame installation works are started. It is recommendable to place as many element groups as possible on top of the foundations.

Truss parts are assembled together on the ground level after which the trusses are hoisted in place. Radiator structures are installed after the main parts of the lower level structures has been installed. Radiator field can also locate in the ground level, in which case the other frame installation works do not schedule it. The reason why the radiator structures are placed on the top of the truss structures is that there is not much free space on a ground level. On the other hand, it can be hard to ensure that the roof is watertight when “radiators on the roof” structure with the high elevation columns is used.

The higher the installation elevation is the more challenging it is to be implemented. One of the most challenging phases of the installation is the truss installation since the span of the truss is usually relatively long. Still, trusses are quickest to be installed after columns. Bracings, tying beams, platforms and other more complex parts instead are time-consuming to be installed.

None of the interviewees have yet used tablets in the projects of Wärtsilä. Instead, some are using laptop for examining the assembly drawings and planning the installation sequence when walking at the site. This procedure has been found to be impractical since the large size of a laptop.

Some of the interviewees are seeing great potential in managing the installation works using tablet. The main advantage is that the assembly drawings can be examining

without constant visiting in the site office. One of the interviewees has also used Tekla BIMsight in other than Wärstilä's project. He found it easy to find elements and to make reports using the software. It also helped him to manage element installation works.

Use of 3D model at the site has offered other kind of perspective for the installation works. Some of the interviewees have used Navisworks Freedom for checking the installation issues, such as clashes, between structural and mechanical parts, and for checking spatial structural data. For example, part levels are examined if the assembly drawings are not clear enough and there are no detailed drawings of the particular installation phase. Sometimes the information expressed in the 2D assembly drawings is not unambiguous enough, so 3D view is needed to be assured of the design solutions.

Some interviewees are also using a Navisworks model for getting an overall picture of the building at the beginning of the project. Instead, it is not used for checking detailed information of single structural elements. Ideally it could be used for making site modifications, site instructions, design changes and clarifications if the site people would be able to work with and edit the model.

5.3.2 Chief Project Engineers

Predetermined installation sequence is pointed out using e-mail conversations and assembly lists and a MASP list. Other lists, such as a container list, or a site plan drawing can be used depending on the project. Some of these documents are also expressing the frame installation milestones as dates.

One of the interviewees is sometimes using assembly lists for helping to solve structural design issues, but this kind of events are quite rare. Assembly lists are mainly created for the use of the supplier and the site team. Manufacturing drawings and assembly lists are delivered straight from the structural design company to the frame element supplier without the constructor involvement.

Installation sequence plan data is used for managing frame element manufacturing and delivery. Deliveries are handled building specifically. It is also checked which kind of extra parts are reserved for the delivery. All the documents required for managing frame element installation including assembly lists should be delivered to the site supervisor before the installation works are taking place. There can be couple of week time frame between the arrival of the containers and the starting point of the frame element installation.

One of the Chief Project Engineers stated that before the installation works are taking place, he is having a conversation with the section manager and they are undergoing the goods that are delivered at the site and the building specified installation order. It is also discussed with the Site Supervisor when the installation works are started is the building level erection order. It is agreed which building is to be built first since it is important to start certain structural works first so that mechanical and electrical installation works can be started. Usually first building to be started is Engine hall or Utility block.

The installation sequence within a module depends highly on the projects resources, such as free cranes, space and men on the site. One basic principle for frame erection of the Engine hall is the following: first frame elements to be installed are all the vertical frame element lines with EGM (Exhaust Gas Module) support structures and main crane beams. These structures are forming first stage frame structure in which the other elements can be assembled at maximum speed if the lifting capacity is sufficient.

Wall and roof panels of an engine hall are usually installed before the radiator field installation is taking place. It must also be considered that the final bolt torquing can be implemented not until all the main elements are on their place. Bolts can be torque even if the wall panels have been installed. In case of the roof panels instead, it is recommendable to torque the lower level main bolt in order to prevent work occupational accident caused by falling roof elements. Frame element assemblies can't be done above the trusses unless roof elements have been installed. On the other hand, some brittle elements, such as far from the frame reaching ladders can be damaged if they are installed too early compared to the main frame elements.

Sometimes you can't install all the frame elements of the engine hall chronologically from bottom to top. For example, side end columns and sometimes some of the inside platforms can't be installed until the engines are moved inside the building. The total amount of these elements is usually relatively small so they can be delivered and packed with other similar elements, and temporary stored on the site.

According to one interviewee, standard installation sequence should also consider work safety: radiator field elements can't be lifted on their place if some work phase on a lower floor is taking place at the same time. This is usually solved by doing the installation works in two or three sections of the engine hall. It is also useful to divide an engine hall to several phases when you are able to see the frame weight of the each phase. If you know how much steel can be installed within a certain time frame you can use this and the weight information for scheduling the overall frame installation.

Usually the site supervisor has the competence to define the detailed installation sequence at his own. Furthermore, there are general instructions for the installation order in the database of Wärtsilä.

Although the building specific installation sequence would have been agreed with the site team and set in the schedule it can be changed during the installation works. For example, subcontractor can first cast the foundation for a building scheduled to be installed in later phase. As a consequence, the scheduled building scale installation order must be changed. It is also possible that the electrical team doesn't manage to assemble earthing on time which will delay the related frame installation works. The customer can also sometimes define his own safety standards which can affect to the erection order of the frame. He can also determine which buildings are first to be built or handed over. Otherwise Wärtsilä can fully decide the installation order.

There is no established system for engine hall phase division. One of the interviewees is usually dividing the hall according to the schedule and related shipments. He is using element type and installation phase based system. This means, for example, mark-

ing the engine hall columns belong to one phase, beams and bracings belonging to other phase, stair tower as its own phase, and so on. The division is based on the experience of the interviewee: he is thinking over the possible installation order and deciding the phase division according to that.

The tallest building on the site is usually determining the size of the crane. Since the project budged is usually really tight, many times there is only one crane located in the installation area. That crane can't be usually used in the laydown area due to long distance between laydown and installation area. Lorries equipped with zip crane are mainly used for moving the frame elements from the laydown area to the installation area.

Weight of the elements in the assembly list is usually checked when the lifting works are being planned. For example, total weight of one truss can be checked in order to ensure that the crane capacity is sufficient. Weight data is also used for progress control, in other words how much steel is installed within a specific time period.

Elements can be tracked in the containers using Logwis, assembly lists or packing lists. Logwis is software for holistic management of whole of the delivery chain from procurement to delivery.

Some of the material can be missing in the delivery or misplaced during the storing period between the unpacking and element installation. If some elements are missing in the delivery it is practical to ask them locally. Also extra parts can be used if there are no local suppliers. If there are not enough extra parts or the parts are wrong types it is possible to find a small supplier in Finland and deliver the elements using an airfreight. The last option is the most expensive unless there is a small amount of elements to be delivered. Even large number of elements can be delivered by air freight if the schedule is tight and the financial impact is significant.

It is usually noticed in the early stage of the element unloading if some of the frame elements are missing in the delivery. Missing small parts that are not main frame elements have usually small effect on the overall schedule. In many cases other elements can be installed even though these parts were missing.

There also have to be extra parts in case of the need of extra supports. Usually extra parts are not used for on-site element manufacturing if the elements are missmanufactured or missing in the delivery. If there are only small manufacturing or design flaws in the elements it is practical to modify them on the site. Big scale design mistakes are rare due to the reliability of Tekla Structures.

Manufacturing mistakes are more common since the manufacturing schedule is usually tight. Frame related manufacturing mistakes are usually related to wrong location of end plates or meshes, or missing meshes. One of the most common manufacturing mistake is that the elements are mirrored compared to the design solutions. Manufacturing mistakes are documented in a diary and delivered for the supplier. They can also be marked in the drawings and be attached to a technical of a failure report.

5.4 Case project: example of challenging packing management

The case site was really cramped: All the buildings belonging to the power plant were located close to each other and the site was located at the center of the city. In addition, there was no room for storing the containers on the site. Maximum quantity of containers at the same time on the construction site was about five to ten and the containers must have been removed from the site once they had been unpacked. Therefore the elements were required to be packed according to the installation sequence.

In addition, there was a separate storage area for the containers that were waiting to be unpacked on the site. Since the schedule was very tight the Master layout of the site had to be locked as early as possible. Also placing the cranes had to be carefully designed in the early stage of the project.

Structural design was implemented and manufacturing drawing were delivered in several phase for the supplier. The engine hall consisting of 12 engines was set to be handed over in four phases, so it was divided to four phases and Utility block as a one phase for schedule and quantity management. Engine hall was divided to two main phases for the MASP list. First of these two MASP list based phases were already designed and assigned for frame element supplier before other phase design was completed. Advantage of this system was that the critical path of the design and delivery was shorter since both design and delivery could be implemented at the same time.

Engine hall division for five phases was not detailed enough for managing unpacking of the containers. One phase must have been divided to three sub-phases which are columns, beams and bracings, and trusses, roof structures and stairs. Columns were packed in the first containers, bracings to the column equipped containers that had still room for other elements and so on. On the other hand, columns for phases 1 and 2 were packed for the same containers so the element division by phases was implemented in a flexible way.

There was two type assembly lists in the project: a main assembly list for the procurement and shipping lists for packing and shipping management. Main assembly list was containing all the frame elements without the phase division. Shipping lists were indicating the division according to which the elements were packed and shipped. The shipping and phase specific assembly list contains three excel sheets, one for each sub phase. These excel sheets were used as set requirements for the packing order. Procurement and logistical management (Logwis) instead were handled by using one sheet assembly lists without sub-phase division. One sheet assembly lists were used for checking out if some elements were missing in the sub-phase division based assembly lists.

There were some challenges in using two types of assembly lists. It turned out that some of the elements mentioned in one sheet assembly list were missing in the sub-phase division based lists. Since the sub-phase division based assemblies were grouped manually in Tekla Structures, human errors occurred and some assemblies. Especially

objects crossing the gridlines were either missing or listed in several sub-phase division based lists.

Besides assembly list, both the project and the site team were using separate list called “container list” for managing sub-phase division based containers. It was a summary of the packing lists delivered by the frame element supplier. The list contained three excel columns: one for internal container number (for example 268), one for common container number (for example CPIU 413632-5), and one expressing the building, building phase gridlines and sub-phase (for example Engine hall 4-6 Columns). This list could be used planning the container transport between the intermediate landing area and the site.

The project was using Logwis for managing most of the delivery related information. The supplier made the packing lists in the software whereas in earlier projects these lists were handled elsewhere and sent as excel files to Wärtsilä. It is possible to track the containers using Logwis during the shipment if the needed delivery and transport data has been updated to the software.

There were three shipments in the project for civil equipment. First shipment consisted of Utility block and first two engine hall phases. Second shipment consisted of first two stacks and engine hall phase three and four. Third shipment included second and third stack and frame elements for all the other buildings.

Containers were stored in a separate storage area located outside the site. It would be optimal if the storage area would be large enough for laying the containers in one layer so that no container would be on top of another. There is a pdf form layout plan document added in Logwis for managing the laydown area and it was made by the logistic guy on the site. It presents the measurements of laydown area and container locations included in it. Before Logwis laydown design and management was handled by logistic guy using excel based systems.

Each one of four engine hall phases consisted of three gridlines stretches and one laydown area gridline stretch between two engine entity groups. The last engine hall phase didn’t have its own laydown area as a gridline stretch. Also Utility block had its own phase. Aforementioned phase division is illustrated in Figure 5.1.

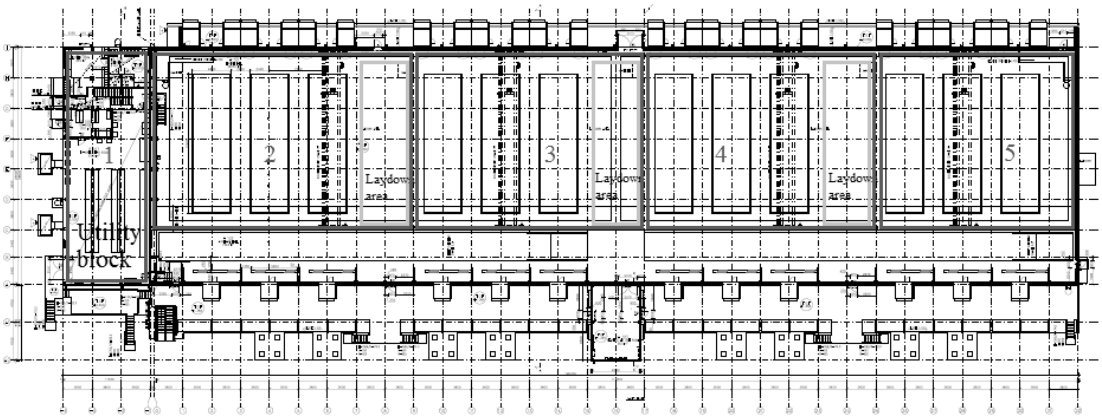


Figure 5.1 *Phase division used in the example project: Utility block as its own phase and engine hall divided to four phases.*

The project was very special as an installation point of view since the engine hall was installed and handed over in several small phases. During the brakes between the installation of different phases the installed part of the engine hall must have been sealed in order to prevent exceeding wind loads caused by the "plastic bag" effect. Therefore the main column between the phases had to be designed for easily removable using bushing bolts. Using this structure they could be easily moved and reused at the end point of the engine hall when finalizing the last phase. This aspect had also to be considered in the management of packing. Other option would have been to use extra steel for the frame of a temporary wall, but that option would have been waste of steel.

5.5 Structural Designer, Technical Expert

5.5.1 Tekla Structures software licenses

Structural designers are using versions 16.0, 17.0 and 19.0 of Tekla Structures at their work. The most commonly used version is 19.0 at the moment. The newest version 20.0 has been tested in the company and it will be started to be use in the near future. Designer specific license type depends on the starting date of the project. Version of the software that was used when the design was started is used throughout the whole project. Model can be only opened with the same or newer version of software that it was originally created.

It is not possible to start to use a new version of Tekla Structures once it is introduced on the marked. This is because it must be first tested profoundly. The structural design company has computer all over the word and it takes time to integrate a new version of the software into the systems of the company. Usage of a new version starts usually around a year or two after it has been launched.

5.5.2 Modeling process during the project

The design company has a Lead engineer that is taking care of the design of steel structures in the project. There is a Chief Design Engineer above the Lead Engineer that is accepting all the structural solutions that has been made. He is also approving all the assembly lists that are printed out. Usually either Chief Design Engineer or Lead Engineer by the design company will send the assembly lists for the frame element supplier. In this case Wärtsilä project team will determine the point of time when the lists are sent.

There is usually a steel designer taking care of structural frame design in the design company. Envelope designer is taking care of the wall panel design usually after the type and location of the frame structures has been locked. These sectors of design are usually modeled separately and also the supplier is separate. In some rare cases, and if the project is small in size, both structural and envelope design can be implemented in a same model by the same structural designer.

Modeling process of the steel structures is usually started in the computation phase of the project. In this phase the model is used for steel weight estimations. The model consisting of raw beams doesn't necessary include any joints between the structural objects. The interviewee is using two models for managing quantities: computation model in one screen and the model for structural design in another screen. In this phase it is evaluated which kind of profiles can be used and what are the spatial limitations in the buildings.

Gridlines for both directions can be chosen in the early stage of the project since they are standardized following the size of the engines. Engine hall main elevations are pretty much standardized in Wärtsilä projects. For example, level of eaves is one of the standardized elevations.

It is not practical to start the modeling process from scratch in every project. Only project properties, such as project name, number and name of the structural designer, must be added every time a new project is started. Models of the old Wärtsilä projects are mainly used as a layout for new projects and buildings belonging to different old projects can be imported in the model of a new project. Using this method you don't have to set object attributes many times since they are standard practically in every project. Especially object prefix information is not usually reset. Also object numbering is intended to keep the same if possible when importing data from an old model. In practical this means numbering only the new objects and keeping the old ones untouched. Existing drawings are also disappearing if you are renumbering the objects presented in the drawings.

Similar projects and buildings are sought both within the structural design company and in collaboration with Wärtsilä. There are also libraries for different building and other structure solutions considering for example wind and earthquake conditions. Sometimes modeling macros, such as joint types, can't be imported from an old version model into the new one and you must do some manual work to solve the issue.

There are written documents of the object naming system that can be used if new objects are inserted in the model. User defined attributes are not used in the modeling of Wärtsilä projects. Every now and then there is some non-standard building in the power plant area with no established naming system. In this case structural designers must invent a proper prefix to describe the building.

Class mark is used to visually separate different types of objects to ease the management of the model. For example, all the columns can be marked using the grey related class number. Class mark can also be used for filtering the objects. There is no standardized system for object specific Class mark and the system varies highly on the personal view and needs of the structural designer. Class number data is not imported in the project documents.

Mechanical model is imported as .dgn file format to the Tekla model in order to combine and set the basis for the structural modeling. This model is containing plain 3D object of all the main mechanical parts, such as engines, and the location of these parts are defining the structure and location of the frame. Small mechanical parts instead are combined with the structural objects during the project modeling process. Either me-

chanical or structural objects must be relocated or changed usually depending on which of these two options is more cost-effective.

Mechanical and structural models are using the same coordinate system so when mechanical and structural models are united objects are automatically located at the right place. There was a bug in Tekla Structures versions 15.0 and 16.0 causing the mechanical parts being in scale 1:1000 when imported to the software. This bug has been repaired in the later versions.

Structural Tekla Structures model is imported as .pdm to Navisworks Manage for implementing clash checks with mechanical model. Structural model can also be exported as Tekla Web Viewer for examining the model at the site via web server. On the other hand, there hasn't been much interest by the site team to examine the model. Lists and 2D assembly drawings have still large support among the site personnel despite the benefits of using direct modeling information.

5.5.3 Utilizing the modeling information for managing quantities and delivery

The company has its own customized templates for Wärtsilä located in the company's servers. These templates are automatically used when the model is opened. If some of the templates is updated in the server of the company it will automatically be shown for every separate license of Tekla Structures. There are separate advanced Tekla users in the engineering company who are creating and modifying report templates if needed. Template modification can also be implemented project specifically if needed. Report and drawing templates are usually in a file format .xml. Templates can be modified in Tekla Structures using the Template editor. Textual templates are stored as .rpt and graphical templates as .tpl files.

There is no standardized phase division used in the projects but the division system must be agreed in every project. Usually platforms outside the engine hall are set to be in a separate phase compared to the main building. Phase division is manly used for making the model filtering and thus management of drawings and lists easier. Only phase division is used for the spatial building division. Floor and sections divisions or related volumetric objects are not used in Wärtsilä projects. According to the interviewee there aren't likely separate functions for these kinds of divisions in the old versions of Tekla Structures. Phase division is implemented by selecting the desired objects manually in the object view and attaching them to the phase.

Model Organizer tool is not generally used in the company. There have been discussions that the Organizer tool could possibly be used in the near future when the version 20.0 will be taken in use. At the moment model information is utilized by using model filtering and list templates. Model is being filtered by using View Filter. It can be found by right clicking the model area outside gridlines and choosing "Properties… > Object group…". Objects are usually filtered by their assembly name or material. Sometimes list templates are containing integrated filters that are automatically filtering some of the manually selected objects. For example, if you choose all the model objects in to the assembly list, roofing sheets will be automatically filtered out.

Assembly list has a column expressing weight of a main part and a columns expressing weight of fixing. Fixing includes all parts connected to the profile which has been defined as the main part of the assembly.

Assembly lists are created in two phases. First everything else but the objects to be chosen to belong on the lists is filtered out of the model view. Then these remain objects are then activated in the model view. The needed assembly lists form of report and the assembly list template is chosen in the Report window that can be opened by clicking "Drawings & Reports > Create Report…". Same assembly list report template is used in all Wärtsilä's projects. There is also an own customized assembly part list template for the frame element supplier considering the special needs of the supplier. Reports are published as .csv file format and imported to the excel template created in the database visible for both the structural design company and Wärtsilä. PDF version of the assembly list excel file is created automatically once the excel file has been approved.

Besides pages containing the list of assemblies, there is an extra page for material management in the excel form assembly lists belonging to the new projects using Logwis. The design company is using separate software called "Import list generator" for creating excel form assembly lists.

The engineering company very rarely sends the whole model for the frame element supplier. The owner of a model is Wärtsilä so permission for sending the model is always needed. If the model is sent for the supplier it is usually sent via Wärtsilä project team.

Manufacturing drawings are first document to be sent for the supplier. Assembly drawings and lists are created and sent after the manufacturing drawings have been delivered. Sometimes structural designers will print out assistant drawings for the supplier to ease the element manufacturing.

After all the documents have been sent there will be usually questions sent from the supplier to the Structural Designers. Usually they are related to flaw in measurements. After the flaws have been fixed structural designers will send updated manufacturing drawings for the supplier. Civil Chief Project Engineer is usually involved as Cs when these kinds of things are handled.

The interviewee has been involved in a project with large Engine hall and detailed assembly division plan. The engine hall was divided to three phases and each phase had its own assembly list and stating number for the assemblies. Usually there are no special requirements set for the phase division based assembly lists and objects are grouped to the assembly list building specifically.

The frame element supplier asks assembly drawings for managing the packing from time to time. If the lists were designed to consider installation sequence, this should already be considered in the modeling phase using some object attribute.

6 CAPABILITIES AND NEEDS FOR IMPROVEMENT IN INSTALLATION LOGISTICS

6.1 Main frame element supplier – readiness to fulfill predetermined packing order

Elements are packed according to building specified information put in the MASP list. The main frame element supplier in Wärtsilä's projects doesn't use Tekla Structures or other building information modeling software for planning the packing. When additional requirements are set, such as packing based on the assembly sequence in the construction site, the supplier needs assembly lists with suitable element division for packaging. Assembly lists must be equipped with the names of the elements, and element quantity and weight. In practice, instruction for predetermined packing system could mean, for example, an extra column for assembly list indicating the erection sequence.

The supplier has fulfilled the requirements of predetermined packing order earlier by the request of Wärtsilä. For example, in one project the column, beams and roof trusses had to be packed separately. In general, there aren't any established requirements for packing order. Requirements are project specific or there are no such determined in the project.

The supplier attaches metal tags with element name to frame elements so that these elements can be tracked at the site. For internal tracking, supplier uses stickers with barcode for internal element tracking. Barcode marking for the request of a customer is not commonly used.

6.2 Needs for improving current packing system as constructor and site point of view

6.2.1 Site Supervisors and Section Managers

According to the interviews, current assembly number marking system is sufficient for all the element tracking. Since the projects are mainly located in the Third World, metal tag marking system is at least sufficient as long as the packing lists equate the content of the containers and the elements are logically divided to the containers. Usually when certain type or size of element is being searched, only rough glance to the element is needed to allocate the element instead of reading the metal tag element by element.

According to one interviewee, the requirements for the systemized packing should be set when placing the frame element delivery order. Setting a systemized packing order will decrease the amount of work in the site by speeding up the element grouping.

Before setting the requirements, project teams should be in contact with the civil supervisor or some other person responsible for the installation works. Other option is that the chief project engineer would plan the installation sequence. Sometimes the predetermined packing systems can fail, if the elements are not manufactured on time, for example, due to the congestion in the element painting area. In this case, there should be flexibility in the packing and installation systems.

Uncontrolled packing order is problematic regardless of the size of the project or the size of the laydown area. It would be good if the packing of the elements would be building specific and continuing by the containers. Furthermore, it would be important as a frame installation point of view to have the fasteners, railings and other small parts packed at least in one or several separate containers. Erection sequence based packing would be even better system and could be based on the modular gridlines. On the other hand, structure of an engine hall in Wärtsilä's projects is quite simple and there is no need for detailed, element specific requirements.

According to one interviewee, it could be useful for structural parts to be packed using the wooden mezzanine and the light weight items on the bottom layer. This would be especially handy in case of packing the columns. Using this kind of packing system would enable the container needed in the next assembly phase to be moved to the assembly place, so that the items could be unloaded and installed directly from the container. Also patch painting could be avoided or at least reduced: element are usually suffering some surface damage when relocated many times.

Other main packing related issues is that the elements are packed and wedged so tight that dragging the element out of the container is a hard and time consuming task. On the other hand, it is necessary as a transport point of view to pack the elements tightly so that the elements are not moved or damaged. Still, it would be recommendable if the supplier would focus more on packing the containers so that they would be easier and quicker to be unpacked. Supplier should also take consider the fact that the construction sites do not necessary have same equipment, such as hoists and industrial trucks, that the logistics department of the supplier does have.

The strength of the current packing system is that the utilization rate of the space inside the container is relatively high. Also the maximum capacity of the container is often nearby reached and the overall number of the containers has been minimized. Better packing order has been achieved in individual projects, but the success depend on the devotion of project manager, project engineers or other person responsible for setting the requirements for the supplier.

Majority of the interviews opinion is that there is no need for big renewals in the content of packing lists and the current system is working well. Finding the required elements and related containers is easy when using "find" tool in Excel, if there is only one packing list in a form of single Excel sheet. Sometimes it would be useful to see the element weight in the packing list if the elements are packed together. This information is required by the contractor when lifting the element packages out of the container. LxWxH (Length x Width x Height) information is not usually needed in the case of

unpacking the steel elements. It is more useful when unpacking boxes containing small items.

One of the interviewees presented a following vision of container unloading and frame installation management system: The software system would link 3D model to the assembly list, to the packing list and to the container layout in an interactive way. The following kind of system would be ideal: The site supervisor would have 3D model on his laptop or tablet. When clicking on the member that is wanted to be installed the software opens assembly list and packing list and highlights the chosen elements. Also interactive container layout expressing the container location in the site would be a good idea. It could be able to highlight the position of a container with the chosen element in this layout.

This kind of system would lead to more facility management type of system. Installed members could be reviewed graphically in the 3D environment in several ways. It would be useful to evaluate building progress by calculating the number or percentage of building specific members that has been installed. It would also be good if an inventory of the containers in the container yard could be done using the same system. This would express which elements with related containers have been installed and what have been not.

6.2.2 Chief Project Engineers

The way of packing by the supplier has changed a lot during the last years and major efforts to improve the physical packing have been already made. Back in the old days there was no wooden material between frame elements or frame element packages. Therefore patch paint was often required since the elements were scratching each other. Nowadays frame elements are bundled together with wooden material between them and also wooden layer structures are used between packages. Use of wooden material has reduced the demand of patching paint. Wooden material doesn't reduce the potential free space for the frame elements since only about one third of the container space is filled with steel to achieve the maximum filling rate of 20 tons.

Frame elements should always be packed in the way the elements are easiest to be dragged out of the container on the site. In many cases a crane is required so that the elements from the open top container can be unloaded. On some sites there are not enough cranes and alternative vehicles, such as industrial trucks, must be used for getting the element out of the container. In this case there is a high risk for paint and other surface damages.

One of the main issues in frame element delivery is that the success of the packing depends totally on the project team at the moment. Project team must agree with the supplier the packing order of the delivery. There is also a financial point of view what it comes to pre-defined packing order: Element packing using detailed packing requirements can be expensive in small projects since the frame element supplier may charge of the extra work caused by the requirements. Therefore, the desired packing order should already be considered in the structural design phase so that it could be realistical-

ly implemented. If it is demanded not until the elements are started to be packed there will be much extra work for the supplier.

There is no established system whether the packing order requirements are charged or not by the supplier. The terms must be negotiated project specifically. Especially in large projects it is likely that the extra costs can be negotiated off due to the large volume order. On the other hand, in large volume deliveries the intermediate landing place in the supplier's workshop may not be sufficient and there is a big pressure to pack some of the containers before all the elements has been manufactured. In this case detailed packing requirements may increase the costs.

Whether the engine hall is needed to be divided to phases depends highly on the project size and number of the containers to be delivered on the site. Detailed phase division is not needed if there is enough free space on the site for storing the containers and the project schedule isn't exceptionally tight. The element manufacturing capacity of the supplier is limited and in large size projects frame elements are usually divided to many shipments so that both the supplier and the site team can better manage the delivery.

Elements belonging to different phases should not be mixed in the same container. Elements belonging to later phase can be damaged or lost if they are stored temporarily on the site for a long period. Storing these elements back to the container is not practical since it is rational to sell the containers as soon as they have been emptied.

If the installation sequence based packing is used there is a risk that more containers would be needed to carry out the frame element delivery and the delivery costs will be increased. On the other hand, it is reasonable to pack frame element according to "from bottom to top" installation sequence if the project is large enough. There have to be enough similar type of elements in one package so that they can be packed in one container. It must also be ensured that there won't be too many types of elements in one container.

Standard installation sequence number based assembly division could be useful if it is easy to implement and not much extra work is required by Structural Designers. The packing requirements could be presented, for example, as a one extra column in the assembly list. Installation sequence number specific assembly lists could also be used depending on the project. In a small project that has sufficient laydown area there is probably only little benefit of the system. Laydown area management has already become easier thanks to Logwis.

6.3 Needs for improving current frame installation protocols

6.3.1 Site Supervisors and Section Managers

Success of the frame installation depends highly on the country and the installation team. Site supervisor has also a major effect on the realization of the installations. Still,

there are no major weaknesses in the current frame installation procedures. Once the installation work has started, the critical path in the schedule is not based on the civil works. Frame design solutions are also mainly standardized and relatively simple so there are not so many challenging aspects in the details. Therefore there has been no need for any major changes in the installation procedures and design solutions lately.

However, according to one interviewee, it would be interesting to see if any parts could be pre-assembled in the workshop. The general principle is that any work that doesn't have to be done in the site saves construction time. Saved time in construction also means decreased risk for errors, quicker erection and more limited risk for delays, which would also mean decreased risk of delay penalties.

Both the quality of the element manufacturing and element assembly is usually in higher level in the factory compared to the site. Any connection done on the site does not only need installation time but also time to do the bolt torquing, to check the torquing and to do the paint touch up. Rule of thumb is that the bigger and more welded and preassembled parts transported in the site are, more time is spared in the installation phase. Naturally there is a limit to pre-assemble bigger parts what it comes to the transport and handling capacity.

As the Power plants are getting bigger and bigger, one design mistake means a lot of extra time consumed for an installation and site modification. If the mistake concerns for example small bolted stubs or small supports, this would have been discovered in the workshop instead of on the site in the case of part pre-assembly. In general, major structural design errors can be better filtered out in the factory when using pre-assembly.

One of the interviewees sees that expressing a very detailed installation sequence in the documents can be risky since it is possible that a construction worker doesn't understand the guidelines. The site supervision of the work usually knows more about detailed installation protocols and requirements, but tells only the necessary information for the workers. The site supervisors have the broadest knowledge of the requirements, but they in turn don't share all the information with the contractor's supervision of the work. Also the boundaries in the language can prevent effective sharing of the information.

In the worst case the customer will read all the detailed installation sequence requirements and prevents making any changes or alternative solutions on the sequence plans when they are needed. This will make the actual installation work difficult and time-consuming since much of the site supervisor's time is already spent for explaining installation and unpacking related work by the hand for the construction workers.

Frame installation animations could be used together with the installation instructions. For example, they could be used for demonstrating the locations in which the columns and bracings are first to be installed. On the other hand, Civil Supervisor are experienced and familiarized with the installation protocols, so no major benefits for the personal use of a Supervisor would be achieved using the installation sequence animations. Instead, in many developing countries detailed installation order and assembly means

needs to be explained for the contractors step by step. Therefore detailed animations presented for the construction workers could be useful.

6.3.2 Chief Project Engineers

Frame is relatively simple and easy to install and there are no major needs to improve the installation protocols. Project specific installation instructions should instead be improved. Instructions for the way and order of bolt assembly especially should be united. At the moment they are briefly mentioned in the general installation instruction of the company: there is a list of bolt sizes and related torques. Torques could be marked in the project specific assembly drawings in order to ease the installation works. Also the planned installation sequence with the torquing order and moments could be mentioned in the drawings indicating the gridlines. Alternative torquing options than moment key should also be introduced in the documentation in case that moment keys can't be used at the site.

Assembly specific installation sequence number located in the assembly list is considered to be a good idea. Standardized installation sequence number system would also set a requirement for the structural designers what it comes to the erection plan, and no extra written-form erection plan would be necessary needed. At the same time it would be recommendable to get a figure form illustration of the intended installation sequence project specifically.

Phase, section or floor mark attached for each assembly is useful only if the type of assembly varies a lot. On the other hand, the more assembly location related information is available the less work hours are needed by the site team for tracking the elements, planning the erection order and supervising the work. Usually there is only small number of different kind of assemblies within one assembly mark so more attributes pointing out the assembly position is not necessary needed.

7 BIM BASED COMMUNICATION PROTOCOLS AND TOOLS

7.1 Code of BIM based communication

There is a common and wrong view that BIM type of collaboration is based on integrated BIM that is holding all the modeling information of all project stakeholders (Figure 7.1). In reality, communication and collaboration among the project stakeholders is based on open BIM (Figure 7.2). This means that structural and MEP design teams of the project are controlling master modeling data in their own modeling applications. These applications have their own file format and it cannot be open directly in other modeling application. Part or all of application specific data can be published as an IFC or other collaborative file format model. This modeling data can only be modified by the application in which the data has been crated. Integrating IFC model is a combination of these data-selected or filtered models. Data between the design stakeholders is transferred using import and export functions. [9]

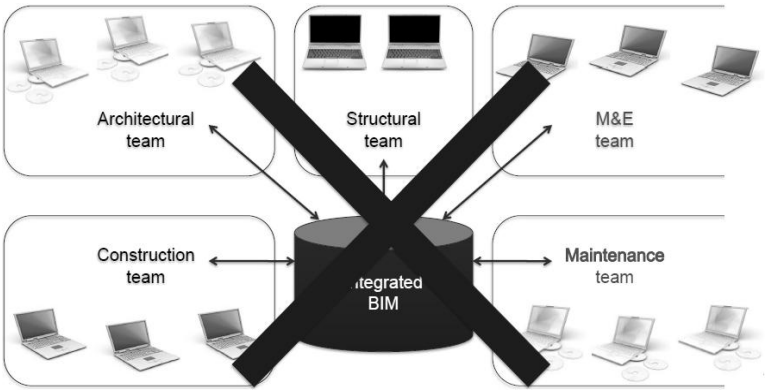


Figure 7.1 *Common and wrong view of integrated BIM.* [9]

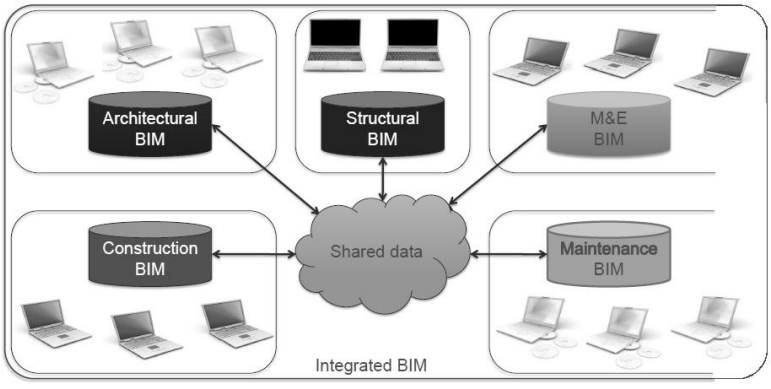


Figure 7.2 *Domain specific and integrated BIM.* [9]

7.1.1 Note files

Notes can be created, shared and replied in note browser of Tekla BIMsight. Notes available in the model are presented in Notes tab. Click "Add Note" icon in the Notes tab to create a new note (Figure 7.3). You can enter a type or a tag for it. You can also write a description for the note (Figure 7.4).

The note can be set to be either public or private (Figure 7.4). If it is set to be private the note file is saved to "PrivateComments" folder located in the project folder. If it is set to be public the note file is saved to "Tekla BIMsight model > ProjectData > notes" folder in the project folder.

Objects can be linked to the note by selecting them in the model view and clicking "Link to selected" icon. Also markups and distance lines can be added using "Distance" and "Marker" icons. A photo of the current model view is attached to the note by navigating the desired view and clicking "Add Current View" icon. Save the note by clicking "Save" icon. Aforementioned steps has been presented in Figure 7.4.

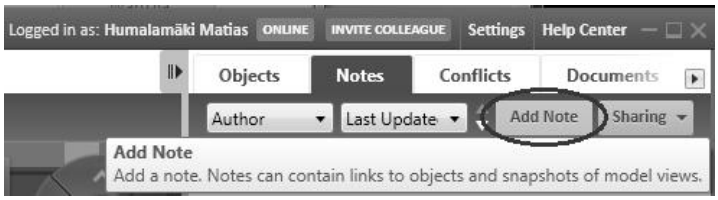


Figure 7.3 *"Add Note" icon in note browser.*

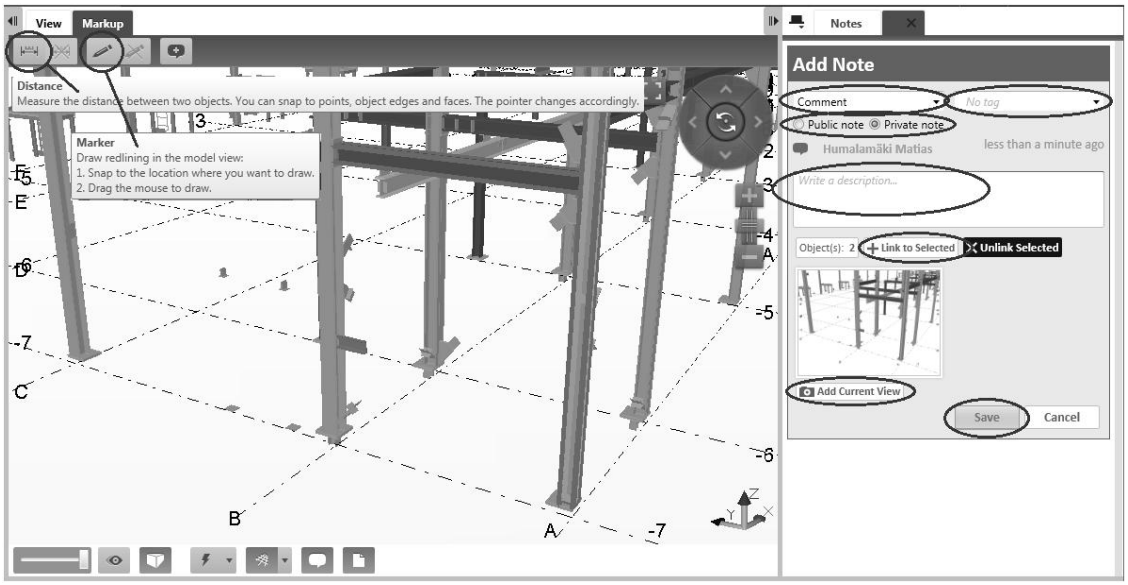


Figure 7.4 *Steps to create a note.*

Notes can be grouped and sorted by type, tag, author, creation date, last update, read/unread status or public/private status. They can be sent as e-mail, saved to desired file in the hard disk or imported by clicking "Sharing" icon in Notes tab. If you click

"Send as E-mail" the software will automatically create an e-mail with the selected notes attached as note files. E-mail application in which the e-mail is shown is Outlook or other application that is set to be the default tool in your computer. If you click "Save to File" you can save the note to some other than the default folder. You can also import notes from the desired hard drive location by clicking "Import Notes". Note sharing options with example grouping and sorting options in Note tab has been illustrated in Figure 7.5.

Figure 7.5 *Note sharing options in Notes tab with selected note grouping and sorting options.*

Note compatibility between different models and revisions is based on "viewpoint.bcfv" file (Figure 7.6). This file is included in the *.bfczip note file if the note is published as a separate file. Viewpoint.bcfv file embodies the data for the navigation for the camera viewpoint and direction in the model view followed by double-clicking the pictures in the note.

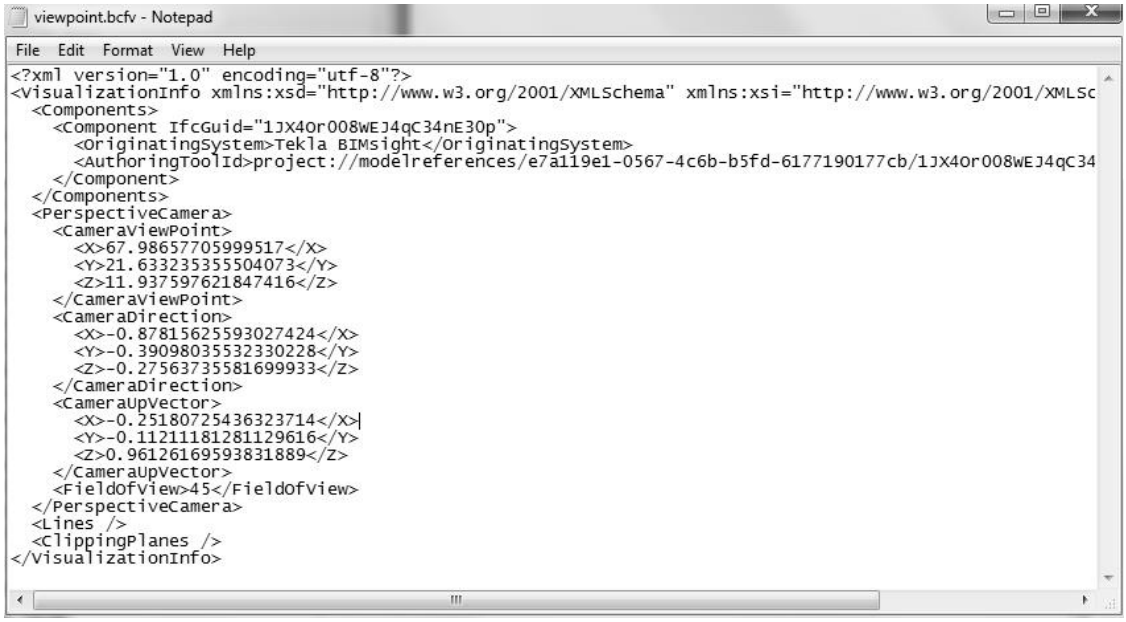


Figure 7.6 *Note file related viewpoint.bcfv file.*

You can examine the viewpoint.bcfv file by following the next steps: Delete "bfc" part from the *.bfczip" file format name of the note. This action will convert the note to zip file. By opening the zip file, you will have access to viewpoint.bcfv file. In addition, you can examine note pictures as "snapshot.png" file and "markup.bcf" file containing other than viewpoint coordinate markup information. Steps to access viewpoint.bcfv file has been shown in Figures 7.7, 7.8 and 7.9.

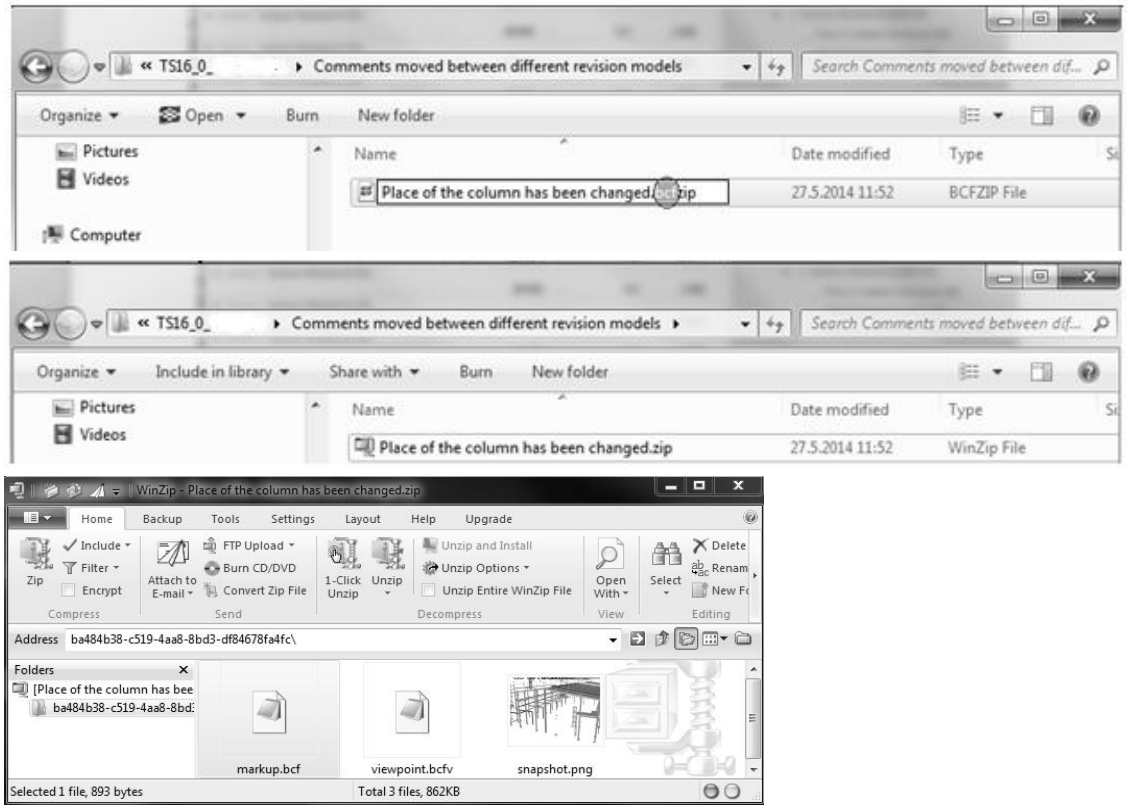


Figure 7.7, 7.8 and 7.9 *Steps to access viewpoint.bcfv file.*

7.1.2 Tekla Structures extension: Comment tool

Communication between Tekla Structures and Tekla BIMsight is taken care of by using note files. Tekla BIMsight does include all the tools for handling the comment files by default. In Tekla Structures instead, separate Comment tool software extension available in Tekla extranet must be installed in order to manage comments. [1] Once Comment tool has been installed a CommentTool icon will appear in Tekla Structures tool menu (Figure 7.10).

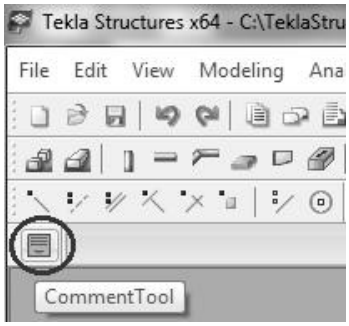


Figure 7.10 *Comment tool icon in Tekla Structures.*

Comment Tool contains a list comment created in the local tool and comments received from other stakeholders that have added their comments in the share folder. The tool contains icons for creating and deleting comments, refreshing comment list, adding re-

draw mark in the model and attaching it to a comment, and filtering comments based on the text in the comments (Figure 7.11).

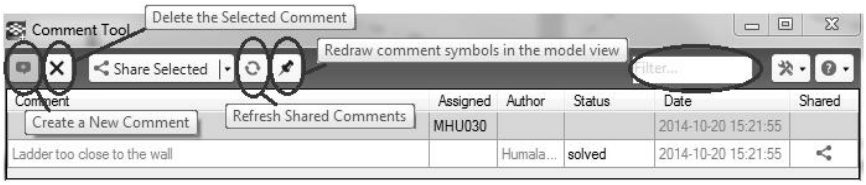


Figure 7.11 *Tools in Comment Tool.*

Comments are private by default. They can be shared by selecting the desired comments in the comment list and clicking "Share Selected". By clicking "Set Share Folder" you can set the location in which the comments are stored as note files. If all the stakeholders have set the same location new comments are automatically updated in the comment list once their status has been selected to shared in Tekla Structures, or public in Tekla BIMsight. Structural Designer can also choose whether he is sharing the note as Tekla BIMsight note by clicking "Share as Tekla BIMsight notes", or just as a Comment tool note. Aforementioned properties has been illustrated in Figure 7.12.

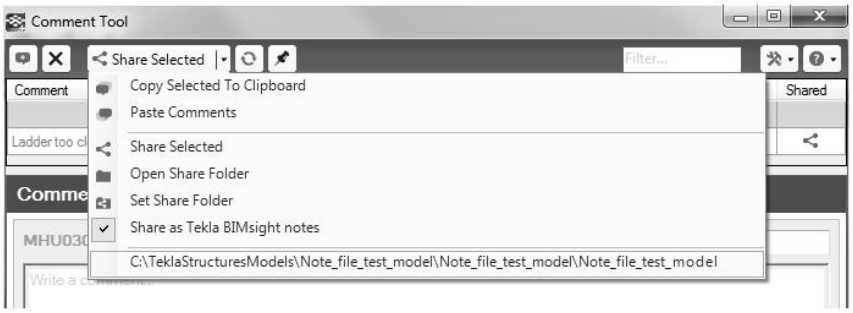


Figure 7.12 *Tools for sharing selected notes, setting the share folder and choosing whether a note is shared to Tekla BIMsight.*

Comment Tool conversations are presented in a comment list containing comment name, assigner name, author name, status and a date for last post in a conversation. Furthermore, it is expressed in the list whether the comment has been shared or not. When creating a new comment, you can write a comment as text description, attach objects, comment status and view as a picture for it. View can be updated if you want to change the related perspective in the model view. Selected objects are presented in the view. You can also edit the picture in Paint software or delete it. For sharing the comment or replying to the previous comment click "Share" icon. An example of a note conversation in Comment tool has been presented in Figure 7.13.

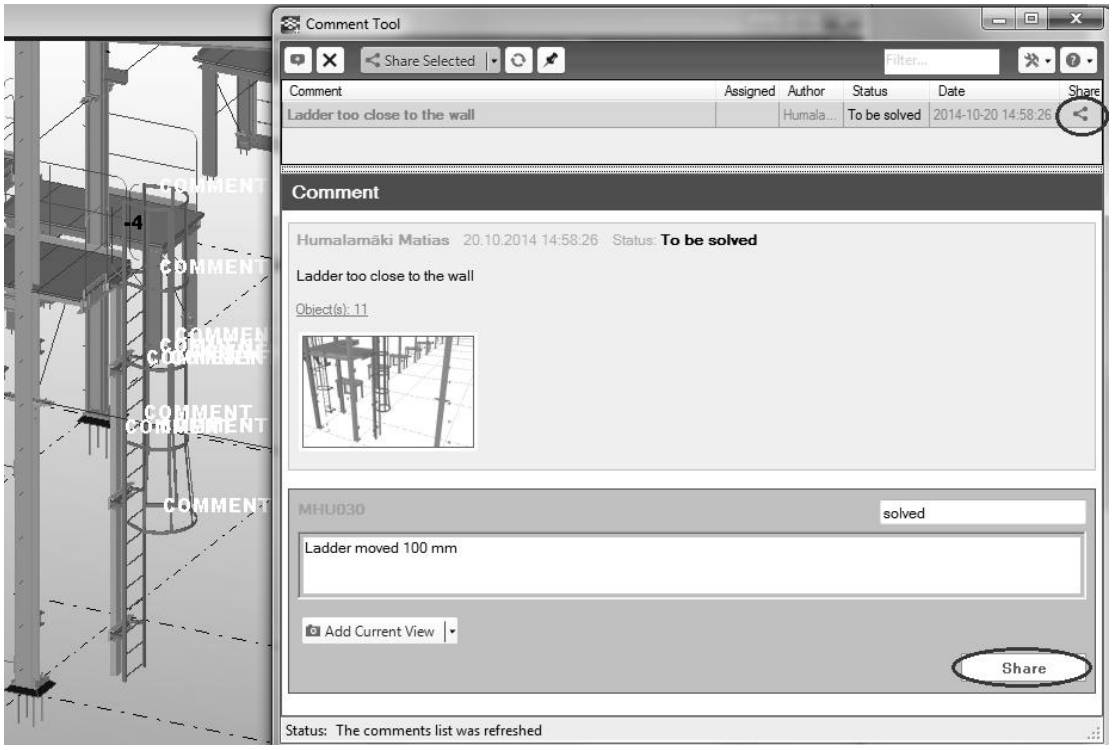


Figure 7.13 *An example of a note conversation in the Comment tool.*

7.1.3 MEP reference model

In power plant construction process, mechanical structures have a major role in structural design and structural solutions. Therefore, it is important for Site Supervisors to be able to inspect outlines of the mechanical structures. Both Tekla Structures and Tekla BIMsight enable inserting reference model with plain geometrical information of the mechanical structures.

There are two different ways of publishing structural model with mechanical reference model in Tekla BIMsight. Reference model can be imported to Tekla Structures after which both of the models can be published as one Tekla BIMsight model file (Figure 7.14 – Option 1). Other option is to export mechanical reference model into the Tekla BIMsight project folder (Figure 7.14 – Option 2). Folder can locate either in local hard drive or in cloud. In this option Tekla Structures model is exported as IFC file and saved in the project folder. Models located in the project folder can then be uploaded to Tekla BIMsight project session and be saved as a package to create one file Tekla BIMsight model if needed.

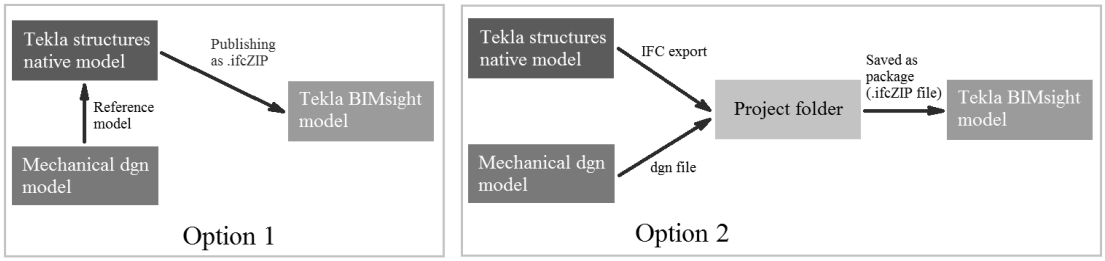


Figure 7.14 *Options to create a Tekla BIMsight model with structural and mechanical objects.*

Benefit of the first option is that there is no need for a project folder. Tekla BIMsight model is also easy and quick to publish. The deficiency is that there a limited quantity of attributes that can be presented as Tekla BIMsight object attributes or that can be presented in object grouping and sorting field. First option can only be used between design team and project engineers in early stage of the project when the design is taking place. Benefit of this option is that Structural Designers can inspect MEP model in their structural model. As a result, they can better manage questions regarding structural and mechanical compatibility.

7.1.3.1 Option 1: importing mechanical reference model to Tekla Structures model and publishing it to Tekla BIMsight

Reference model can be added to Tekla Structures by clicking "File" > "Insert reference model" and choosing the reference model file in the folder tree view. Next a point must be picked for placing the reference model in the Tekla Structures model. The picked point defines the reference model origin. If the structural and mechanical have the same origin point, you can pick the Tekla Structures model origin. Mechanical reference model consist of one object containing only Object ID. Therefore it only indicates geometrical shape of the mechanical structures. This information can be used to avoid clashes between mechanical and structural parts. An example of mechanical reference model with structural model in Tekla Structures has been illustrated in Figure 7.15.

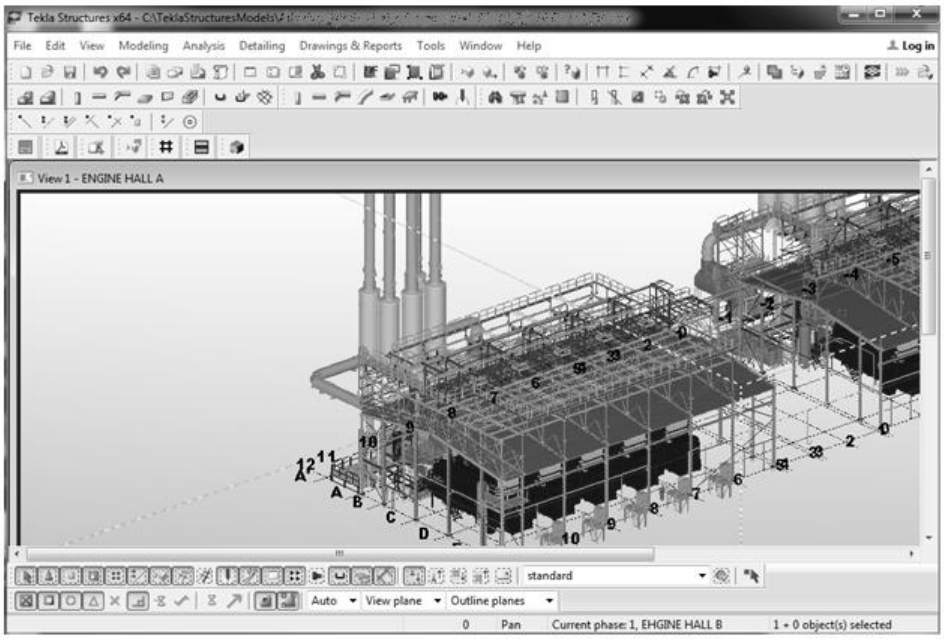
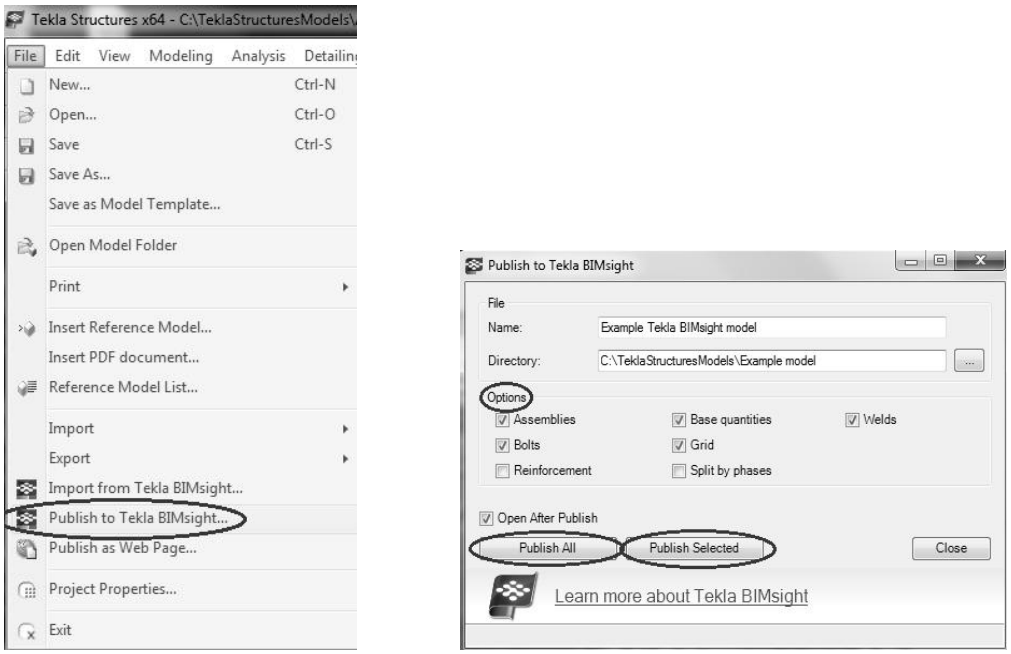


Figure 7.15 *An example of combined structural model and mechanical reference model in Tekla Structures.*

Tekla Structures model with mechanical reference model can be published by clicking "File" > "Publish to Tekla BIMsight" in Tekla Structures. Next you can choose all the Options you want to publish. After this click "Publish All" icon. You can also optional-

ly click “Publish Selected” icon if you only want to publish part of the model. These steps has been shown in Figures 7.16 and 7.17.



Figures 7.16 and 7.17 *Steps to publish Tekla BIMsight model with selected options.*

Now both structural and geometrical mechanical objects are shown in Tekla BIMsight view (Figure 7.18). Gridlines and structural model are in ifcZIP file format and mechanical model in dgn file format. Mechanical reference model consists of great number of separate mechanical objects, but these objects don’t include any more information than their geometrical shape and GUID mark.

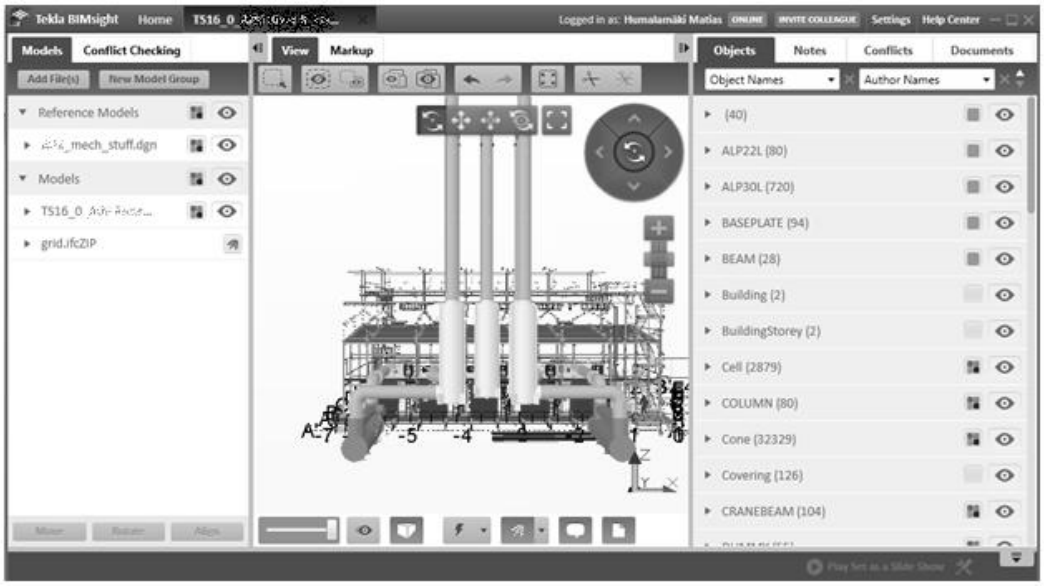


Figure 7.18 *An example of structural Tekla Structures model and mechanical reference model published as Tekla Structures model.*

Although the reference model is now shown in Tekla BIMsight project session, it is not shown in a new location when the Tekla BIMsight ProjectData.tbp file is copied and sent via e-mail. This is because reference model is still not included in the Tekla BIMsight model and the link between the Tekla BIMsight and the reference model is broken. Therefore, project must be republished by clicking "Save as a Package" in Home tab of Tekla BIMsight (Figure 7.19). The new package file containing all the separate models can now be shared with project participants.

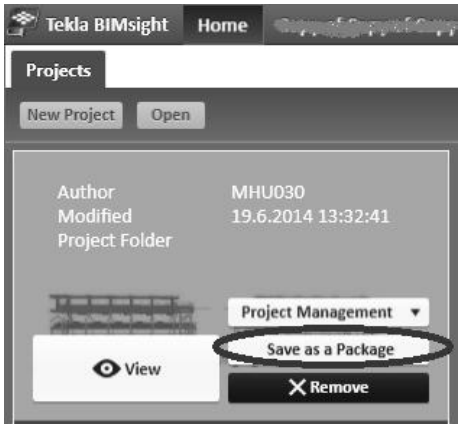


Figure 7.19 *Project specific "Save as a Package" icon in Home tab of Tekla Structures.*

7.1.3.2 Option 2: exporting mechanical reference model and to Tekla BIMsight project folder

Using this option you can export Tekla Structures and MEP reference model separately to Tekla BIMsight project view. First you will create a new project by clicking "New project" icon in Home tab (Figure 7.20). You can name the project as you desire (Figure 7.21).

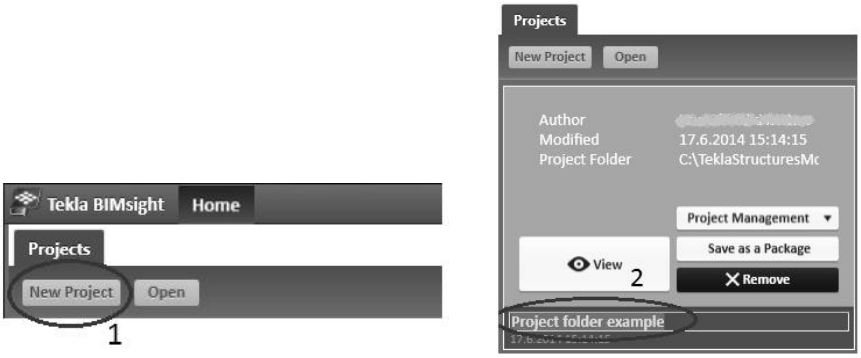


Figure 7.20 and 7.21 *Steps to create a new project in Tekla BIMsight*

Next we will set the project folder. To create a new project, click "New Project" icon in Home tab in Tekla BIMsight. Then click "Project Management" > "Project Folder" in the created project and choose the desired project folder location in your computer hard drive (Figures 7.22 and 7.23). Location can also be a cloud folder such as Dropbox. In our case, folder includes project structural model in IFC format and mechanical model in dgn format (Figure 7.24).

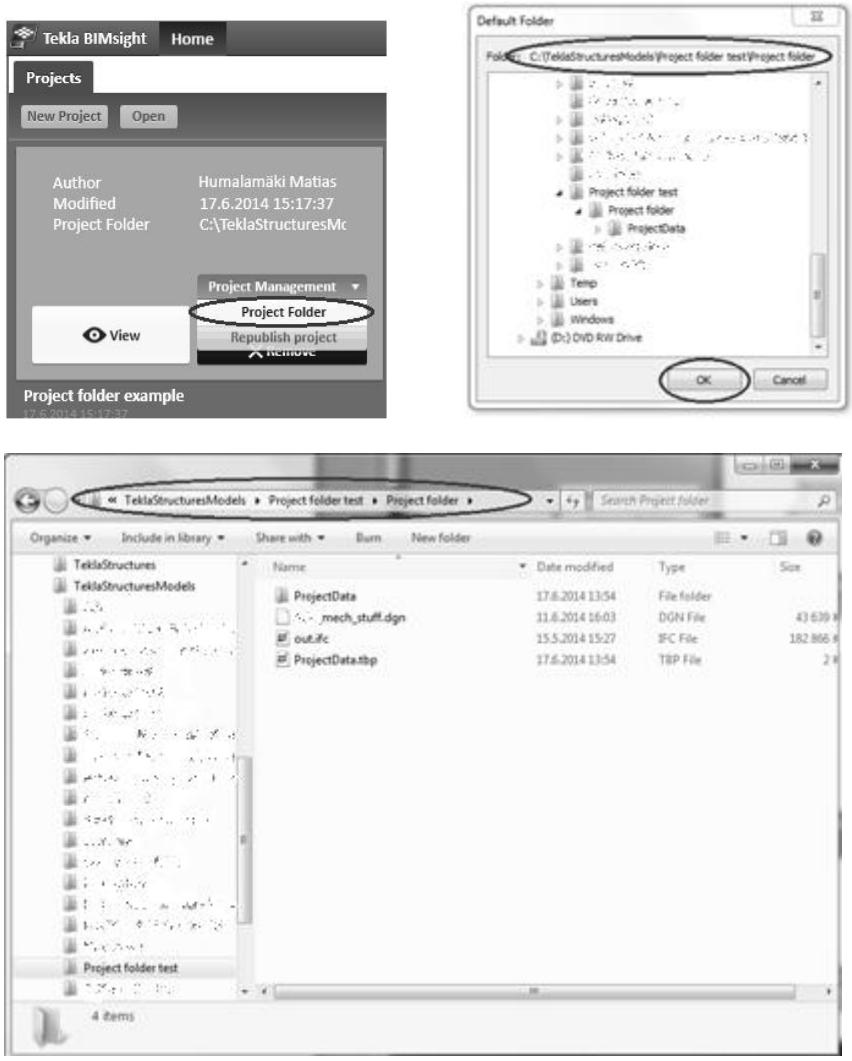


Figure 7.22, 7.23 and 7.24 *Steps to set a project folder in Tekla BIMsight.*

You can now see that the Project folder has been set in Home tab "Project Folder" row. Click then "View" icon to examine Tekla BIMsight project equipped with structural and mechanical models (Figure 7.25). Both structural and mechanical model can now be downloaded to Tekla BIMsight project view by clicking "Load all new models from default folder" icon (Figure 7.26). [10]

Figure 7.25 and 7.26 *Steps to load all the models located in project folder to Tekla BIMsight session.*

Using project folder will also automatically create ProjectData.tbp file storing data created in Tekla BIMsight and a separate ProjectData folder within selected project folder. ProjectData folder includes separate folders for project comments, links, notes, persons, redlines and snapshots. Project folder is project specific, which means that there can be only one project linked to the project folder.

You can add new models or new model revisions to Project folder. If you add a new revision of the model named similarly to the old revision, Tekla Structures will inform you that a model with same name already exist in the project folder. In this case, you can either override the previous revision or create a new revision with different name. If you rename the new revision, model is loaded in the Tekla BIMsight view just like presented in the previous step. Tekla BIMsight will recognize a new revision as same model as the previous revision file if the revisions have the same name. If you will override the old revision, you can execute changes in model view by clicking "Refresh all models" icon in the Models tab (Figure 7.27). You can also update a single model if you don't want to update them all (Figure 7.27). [11]

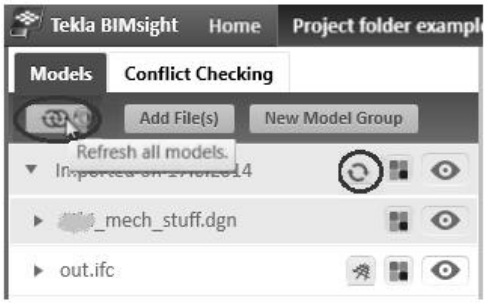


Figure 7.27 *Refreshing either all the models or a single model in Tekla BIMsight project after the updates in Project Folder.*

Tekla BIMsight users can also move models, rotate them or align a model with another model in a Tekla BIMsight project. These changes can be updated for other user by clicking "Republish project" in the Home tab (Figure 7.28). Other users can then update the changes by clicking "Refresh all models" or "Refresh model" icons appearing in their Tekla BIMsight view.

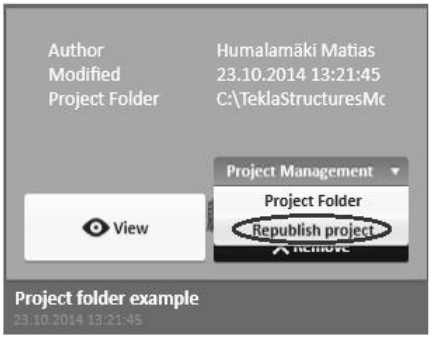


Figure 7.28 *Republishing project after relocating models in the project.*

7.2 Collaboration protocol 1: Dropbox or other similar cloud folder

Tekla Structures and MEP model are first exported to a Dropbox or other similar cloud folder. Notes are stored automatically to the project folder once they are created. Notes between Comment Tool and Tekla BIMsight project view are delivered interactively for other users once they are created and shared. Using cloud folder also enables sharing notes between Project Engineer and site team, and site team and Structural Designers. These notes can contain comments, saved views and markups. Aforementioned protocol is illustrated in Figure 7.29.

In the design phase new revision of IFC and dgn models are exported to the project folder with same name than the old revision had and the old revision is chosen to be deleted in the folder. Old export revisions can be saved in a separate folder created within the project folder. Revision control can also be implemented using note files indicating a revision publishing date. These "milestone" notes ease to perceive in which revision the notes are referring to.

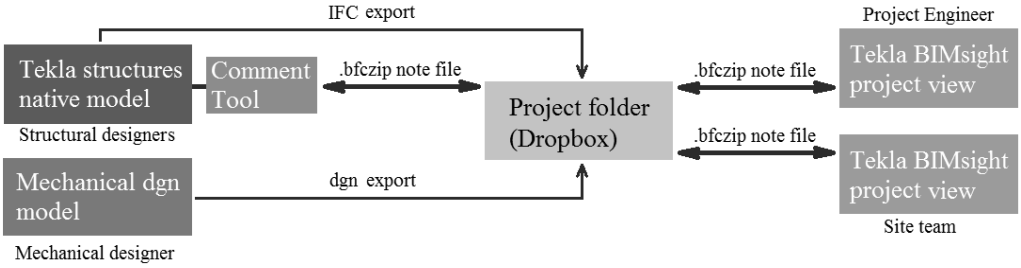


Figure 7.29 *exporting structural and MEP model to a cloud type of project folder, and note file based communication between the stakeholders.*

7.3 Collaboration protocol 2: E-mail and local project folder

7.3.1 Note file communication and collaboration with site team

Note file based communication between Structural designers and a Project Engineer starts when Structural and MEP designers will send IFC and dgn export files for the Project Engineer by e-mail. He will then establish a project folder in which the files are stored. Notes are sent and received using e-mail. They are always manually saved to local hard disk project or other folder. In Tekla BIMsight, comments can be also imported by dragging a comment from the e-mail to the project session. E-mail based communication between Structural Designers and Project Engineers has been illustrated in Figure 7.30.

The revision can be mostly implemented in a similar way than when using Dropbox based collaboration. The difference is that export files must be manually saved to the local project folder.

When the design process is completed structural and MEP models sent by designers are saved under one Tekla BIMsight file by using "Save as package" function. Project engineer will first send this file for the Site Supervisor by e-mail. Communication between Site Supervisor and Project Engineer is based on note files sent by e-mail and other e-mail based communication. After this site team can send questions and comments as note files for the Project Engineer. Project Engineer can forward these questions to the structural designer as same note files if needed.

Attached documents, created views and created markups along with Tekla BIMsight model can be saved as one file and send as a package in e-mail conversation between the Project Engineer and the Site Supervisor. This option is useful if large amount of data created in Tekla BIMsight, such as documents attached to objects and slide show albums, must be sent for other Tekla BIMsight user. Note files can still be used for sending single saved views with created markups. Aforementioned protocols has been presented in Figure 7.31.

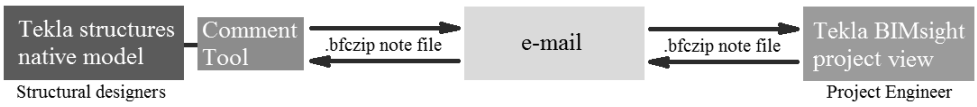


Figure 7.30 *E-mail based communication between Structural Designers and Project Engineer.*

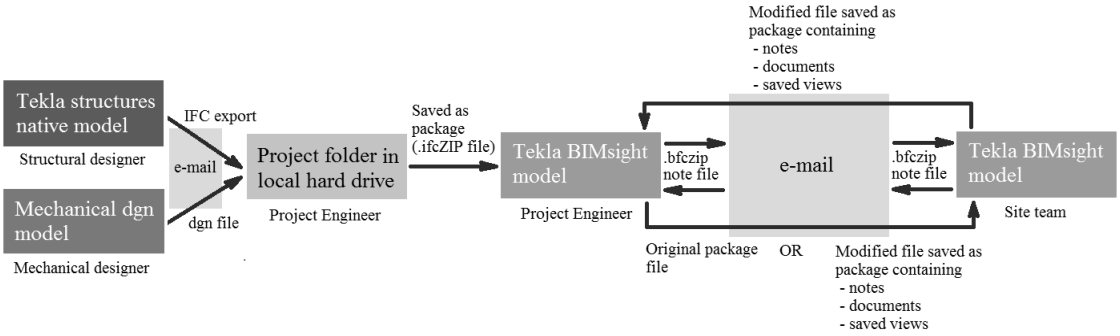


Figure 7.31 *Creating design or installation phase Tekla BIMsight model and BIM based communication between Project Engineer and site team.*

7.4 Collaboration protocol 3: Constructors internal project bank

Communication between Structural Designers and a Project Engineer starts with importing dgn file format MEP model as a reference model to Tekla Structures model. Both models are then published as one Tekla BIMsight model in Wärtsilä's internal project bank. The Project Engineer will then download the model in his local hard drive. This internal project bank doesn't enable establishing cloud type of collaboration using a project folder. Instead, files must always be manually uploaded and downloaded in folders located in this data management system.

Note files can then be sent between the Structural Designers and the Project Engineer by uploading them in the agreed project bank folder location. Notes must be manually saved to the project bank or loaded from the project bank to the local folder loca-

tion. In Tekla BIMsight, you can also double click a note file located in the project bank and the note will be opened in the related Tekla BIMsight project. Also site teams can send and load note files in a project bank if they have access to it. If a site team doesn't have access to the project bank communication between Project Engineers and Site Supervisors is implemented using e-mail just like in the protocol 2.

New revisions of Tekla BIMsight model can be published to the project folder once structural and MEP design proceeds. Revisions are always named after their publication date. Downloading a new revision of Tekla BIMsight model in the local hard drive will automatically create a new Tekla BIMsight project. Different revisions are then seen as different projects as Tekla BIMsight point of view. Project bank based collaboration protocol has been illustrated in Figure 7.32.

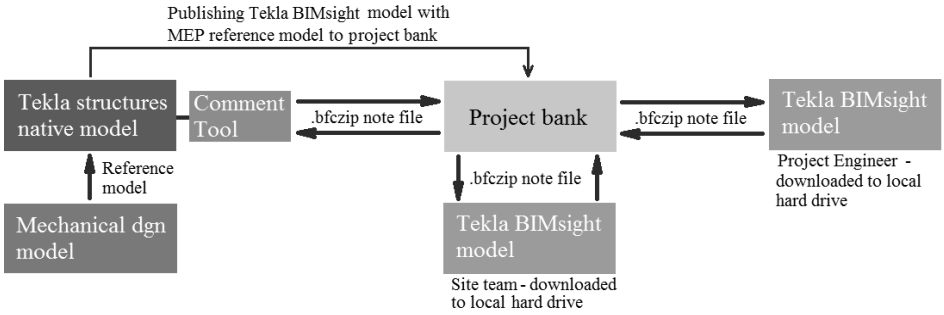


Figure 7.32 *Project bank based note file communication and publishing Tekla BIMsight model to the project bank.*

If the Project Engineer and the Site Supervisor want to deliver created views and created markups with attached documents to each other they have to save the modified Tekla BIMsight model as a package and add it in the project bank. Alternatively, they can send the package as e-mail. This package model is always seen as a new project in Tekla BIMsight home tab. Also separate notes containing saved views with markups can be stored to project folder to deliver object grouping data.

7.5 Summary of the collaboration protocols

Cloud folder is the best option of the presented three protocols. Notes are easy to send and reply in Comment tool or Tekla BIMsight view since they are automatically available for all users in the shared folder. When using e-mail or constructor's internal project bank notes must be manually send or uploaded outside the model view. These two systems also don't enable creating note threads that are easy to follow.

New revisions of structural and MEP model export files are easy to manage if they are saved to the cloud folder or local project folder while old revision files are simultaneously deleted. When using protocol 3 new revision of both models must be published at the same time which is not practical if only one model has been modified. This protocol also requires establishing a new Tekla BIMsight project for every new revision of Tekla BIMsight model. Furthermore, note conversations underwent in the previous revisions must be imported from the project bank if needed to be inspected.

8 FRAME INSTALLATION SIMULATIONS

Simulations can be used in construction site for indicating erection sequence in frame installation visually. Site Supervisor can check the installation order and give instructions to workers using visual animations. Simulations can also be used by Project Engineers to lead both procurement and construction work.

Simulations can be presented in both Tekla Structures and Tekla BIMsight. In Tekla Structures there are many tools, mainly extension tools, to simulate the installation works. In Tekla BIMsight only slide show animations can be used for this purpose. Simulations or animations can't be moved from Tekla Structures to Tekla BIMsight. Next we will introduce simulation features in Tekla Structures and the slide show animation tool in Tekla BIMsight.

8.1 Tekla Structures

There are several both integrated and extension tools in Tekla Structures for simulating an erection sequence. Integrated tool for schedule based erection sequence visualization is Project Status Visualization. In order to use this tool you must create or have a BIM based erection schedule. Extension tools for simulations are Installation Sequence, Construction Sequencer, Erection Sequencer and Tekla Animator. Some of the extension tools are only available for specific versions of Tekla Structures.

Most of the simulations made in Tekla Structures can't be exported outside the software as BIM information. Instead, they can be delivered as videos or other non-BIM based files for the site or project team. On the other hand, structural designers are able to use the simulation tools for making a small scale erection plan if some of the structural solutions or specific nature of the project are requiring it.

8.2 Tekla BIMsight

Frame installation can be animated using slide shows based on the selected views in the model. Slide show can be created and installation can be animated by executing following steps:

1. First we will improve model visibility and object distinguishability. Click "Change the color of the selected objects" icon in the structural model in Models tab and choose custom color (Figures 8.1 and 8.2). Pick the desired custom color and transparency and click then "Ok" (Figure 8.3). In our case, color of the whole model has been changed to grey to improve installation animation visibility.

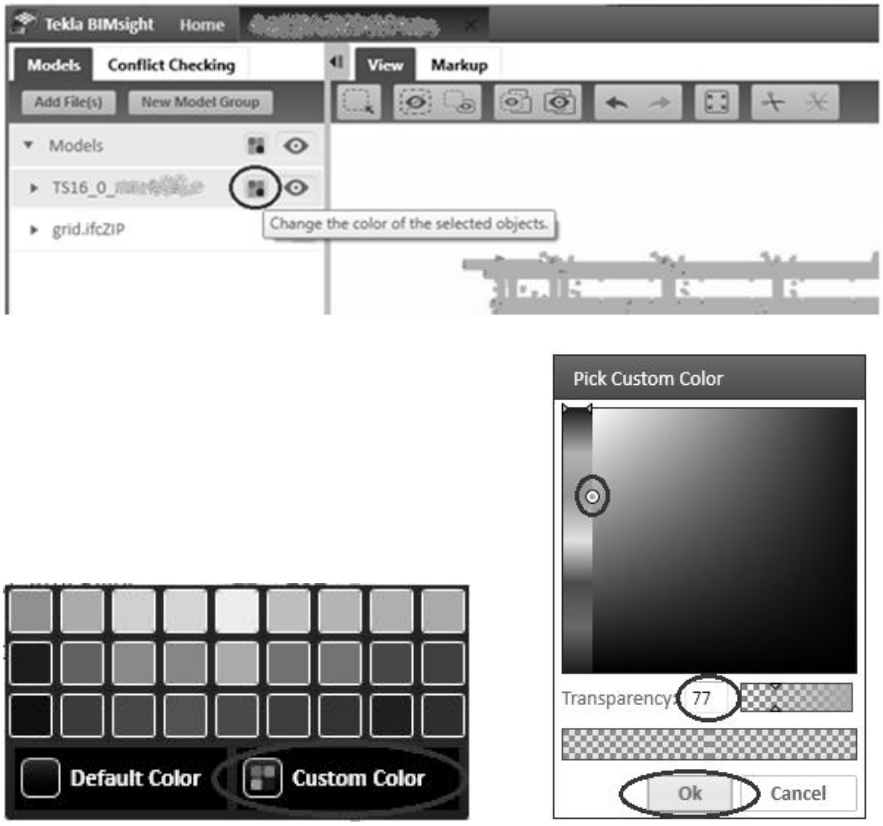


Figure 8.1, 8.2 and 8.3 *Steps to change model color and transparency.*

2. Next we will create a slide show animation of one possible detailed level frame erection order. This example can be used for demonstrating the right erection order for the construction workers so that the requirements set for the engine hall stiffening are fulfilled. In order to get detailed level erection order visible in the model we have manually hidden all the other objects than the assemblies that are presented in the slide show. To hide the desired object, click "Area selection" icon in the View toolbar (Figure 8.4), select the desired objects in the model view, right click one of the selected objects and choose "Hide" (Figure 8.5). In this example all the other elements but columns, support beams, bracings and crane beams have been hidden (Figure 8.6).

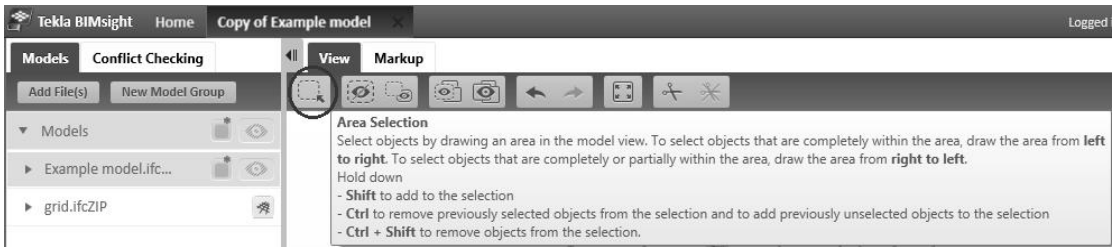
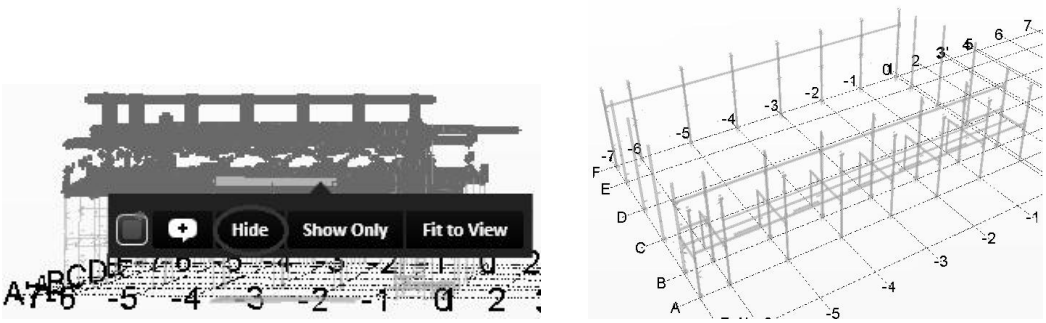


Figure 8.4 *Area Selection icon in the View toolbar.*



Figures 8.5 and 8.6 *Hiding the selected model objects and the view of the engine hall frame after hiding the objects.*

3. Objects that are not needed to present in the slide view can also be hidden using "Clip Plane" icon. Clip planes can be deleted by clicking "Clear All Clip Planes" icon. Location of these icons are shown in Figure 8.7.

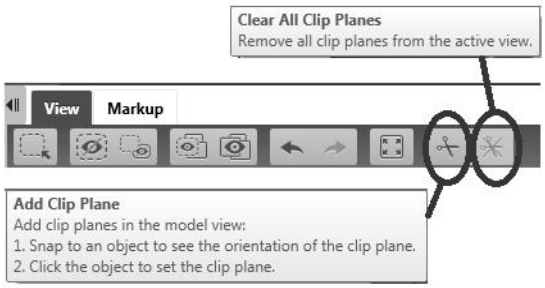


Figure 8.7 *Icons for creating and clearing clip planes.*

4. Slide shows can be created with slide show tool found in the bottom of Tekla BIMsight session. Slides are always using the current model view with selected objects in it. Create two views by clicking "+" icon. Drag one view on top of the other view in order to form a New Group in the Album. Names of the groups or views can be changed by right clicking the view and choosing "Rename" or re-writing the field next to the "Album" icon. In our case, name of the album has been renamed as "Frame erection order example". Aforementioned steps has been illustrated in Figures 8.8 and 8.9.

Figures 8.8 and 8.9 *Steps to create a slide show group.*

5. By double clicking the view group that we created (Frame erection order example) we can have access to the group specific views. In our case there is one

view called “New view” inside the view group. If there wasn’t one or if a new view is wanted to be created we should click “+” icon to create a view. Rename the view as desired in the name field. We have renamed the view as “1” describing the first stage installation. Then choose all the desired objects in the model view, right click the slide and choose “Update”. Steps for these actions has been presented in Figure 8.10.

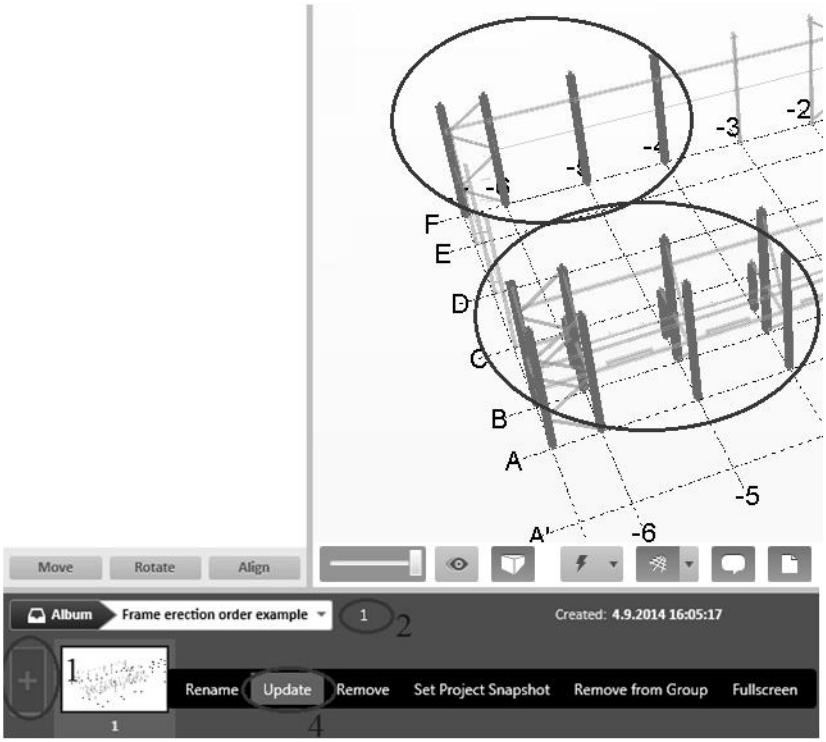


Figure 8.10 *Steps to create a view for first stage installations and to attach related objects.*

6. Repeat the aforementioned steps to create a full slide show animation. If you want to make a cumulative slide show press Ctrl button when choosing new objects in the model view. In our example erection order we have animated the installation works to start from three first gridline stretches, starting from one end of the Engine hall. Next the bracings related to columns, support beams parallel to shorter gridlines and crane beams are installed. Erection order analogous to the aforementioned steps is then repeated for the rest of the gridline stretches. As a result we will have an animation of first stage frame installation works. An example of cumulative slide show animation of frame installation works has been presented in Figure 8.11.

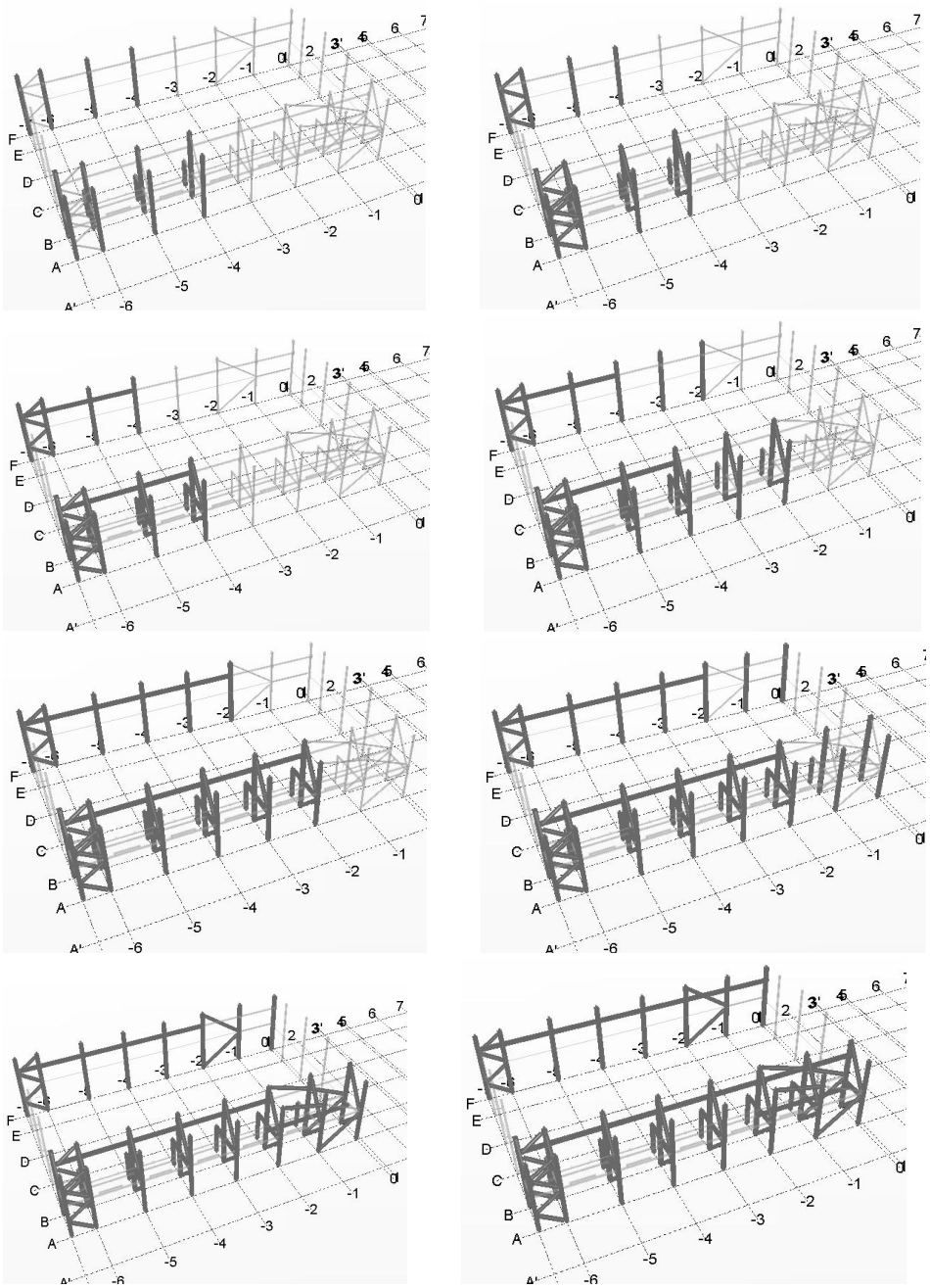
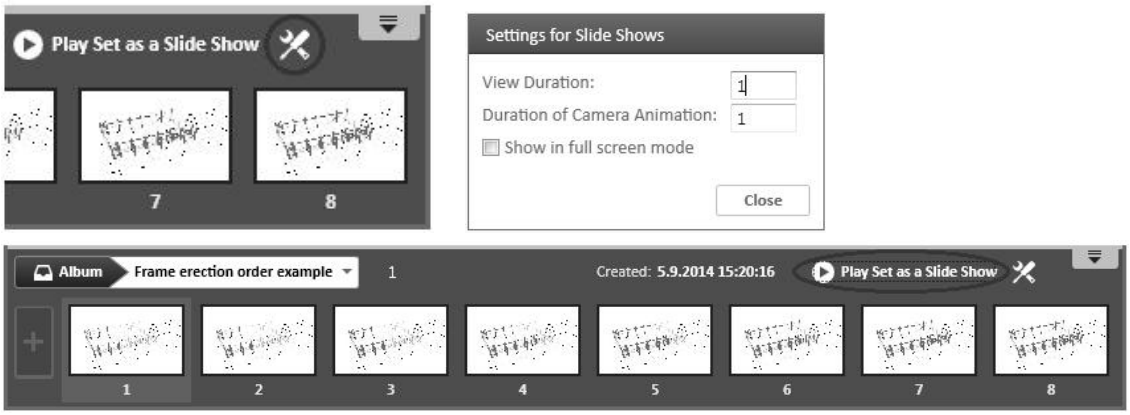


Figure 8.11 *Cumulative slide show animation of first stage frame installation order in the example case.*

7. When all the desired model objects are attached to the related slide views, slide show is ready to be played. You can play slide show by clicking “Play Set as a Slide Show” icon (Figure 8.14). You can also change Settings for Slide Shows by clicking the button next to the “Play Set as a Slide Show” icon (Figures 8.12 and 8.13). If you want to change module based erection order, you can change the order of slide show view boxes by dragging them inside the slide show tool.



Figures 8.12, 8.13 and 8.14 *Route to change slide show settings and to play the slide show.*

8. Slide show slides along with other data created in Tekla BIMsight are automatically saved in project folder after creating this data. If separate Tekla BIMsight model is used this data can be saved by creating a new model of the modified Tekla BIMsight model. This can be implemented by going to home tab and clicking "Save as a Package" in the project related to this separate Tekla BIMsight model.

9. If it is necessary to deliver slide show to the project stakeholder that hasn't installed Tekla BIMsight, it is not possible to export slide show animations as .avi, .mpeg or other video file format. Instead, free screen recording softwares can be used for recording the slide show animation, and the screen recording file can be delivered forward. [12]

8.3 Summary of the frame installation simulation tools

Erection simulation tools in Tekla Structures can be related or unrelated to schedule based modeling information. Tools to simulate erection sequence in Tekla Structures are relatively limited. There is no single tool for implementing automatic, non-manual simulations in the software. Best result can be achieved by combining data created in Organizer tool and separate simulation tool. Even this option doesn't enable whole model scale, object level simulations without large amount of manual work.

Since the animation created in Tekla Structures can't be exported to Tekla BIMsight, it doesn't apply to supervision of the work. In addition, there are no plans to start to use Tekla Structures by the Wärtsilä's project team at the office. Erection sequence tools in Tekla Structures are more suitable for small scale simulations in the design phase of a project.

In Tekla BIMsight there is a separate slide show tool for making the animations. Tekla BIMsight slide shows are easy to create and modify. They can also be saved along with the rest of the project data in one model file when saving the project as package. Object groups created in the Objects tab are easy to attach to the view slides.

You can create either cumulative or non-cumulative frame installation animations. Slide show animations in Tekla BIMsight can be used for detailed level frame erection

simulations. For example, a Site Supervisor can animate next stage installation if the construction workers are unfamiliar with it or if it is hard to implement.

Slide show tool is only designed for user specific planning and storing progress data, and for site management. In order to deliver slide view data for other project stakeholders slide views data must be put to note files. Since many views can be attached to a note it is possible to convert the entire slide show into one note.

Frame element simulation tools can be used if no user defined attributes attached to the objects are used to describe the erection order. On the other hand, implementing simulations is requiring fairly amount of manual work. In the following chapters we will introduce a way to divide an engine hall model to logical volumetric areas and a way to attach installation sequence number for the model objects. Using this system will standardize the packing order and reduce the need for planning project specifically the packing order based on the installation order. Still, simulation tools can be used if more detailed packing design is needed.

9 STUDIED SOFTWARE PACKAGES – PROPERTIES FOR MANAGING PACKING AND INSTALLATION LOGISTICS

BIM based packing system is examined using a Tekla Structures model of an existing Wärtsilä's project. There are five engines in two engine hall modules called Engine hall A and Engine hall B in the case example. In addition, the model contains a stair tower attached to the engine hall A module. The model doesn't contain assemblies belonging to the compressor room structures located between Engine hall A and B modules. Still, it is taken into account in the research because it is an essential part of the building.

9.1 Tekla Structures

According to the interviews, management of both packing and unpacking of the containers is based on the information found in the assembly lists. The frame element supplier utilizes the assembly list for planning the packing and checking that all the elements belonging to the delivery are manufactured and packed in the containers. The supplier has also readiness to fulfill the pre-determined packing order based on the installation sequence data found in the assembly lists. Site team can also utilize the same data. Therefore is practical to find connection between the supplier and the site team through the assembly lists.

There are usually several different ways to create and organize information in Tekla Structures. Chosen method can vary depending on the used software version, protocols of an engineering company, personal desire of a Structural Designer or quantity of data to be managed. Following methods apply on Tekla Structures version 20.0 and are most useful in a case of a large size or a challenging project. In the case of a small and non-challenging project also more conventional model categorization methods are sufficient.

Next we will present step by step how to divide the model to manageable areas, how to add installation numbers to the model objects and how to create an assembly list containing logical areas and installation sequence data can be created. The building will be divided to sections and floors according to the building boundaries, gridlines and building modules. After sections and floors have been created, it is possible to create phases based on the section and floor data. Next the assemblies can be grouped according to the phase, assembly type and the maximum capacity of containers. As a result, we can export an excel form assembly list that is that is utilizing object categorization information created in Tekla Structures.

9.1.1 Organizer: Dividing model to sections and floors

In order to manage model object related frame element packing, assemblies and parts can be divided according to logical areas. Engine hall is divided to section according to column lines i.e. main cross gridlines. In addition, engine hall is divided to three floors. First floor consists of columns, bracings, lower support beams, crane beams, crane platforms door second beams and door platforms, in other words all the main frame structures below the truss structures. Second floor consists of truss structures, in other words roof trusses, roof second beams and inlet support beams. Third floor includes the radiator field above the truss structures and ladders related to the radiator field. Radiator field consist of lower support beams, support beams for cooling pipes, upright beams, horizontal beams for radiator structures and platforms, platforms, and crane beams and related support beams. Both Stair tower and Utility block are divided to one section and one floor.

Steps for organizing the model for location categories in the Organizer tool are the following:

1. Open the Organizer. Right click “Project => Building” category and choose “Define boundary boxes for location” in Categories tab.

2. In the “Building” tab located in the “Boundary boxes for locations” window, default settings for the building boundaries are accordant to the selected gridlines and elevation layers (Figure 9.1). To be able to group objects outside the outermost gridlines or elevation lines, we must manually change the boundaries of the boundary box (Figure 9.2). In our case, some of the bottom objects, top objects and other outermost objects were outside these default boundaries of the model. Model view of reset boundary box has been illustrated in Figure 9.3.

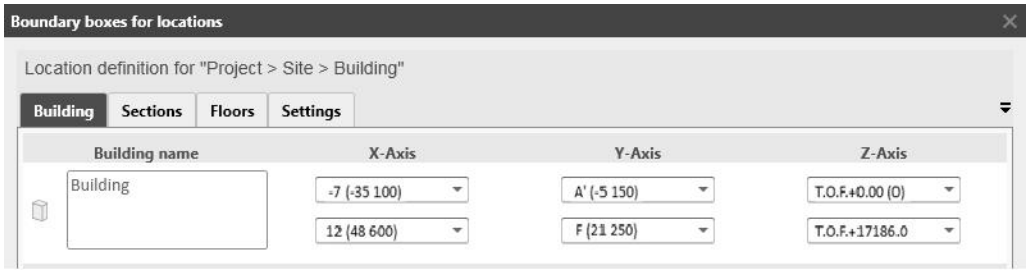


Figure 9.1 *Default settings according to gridlines and elevations for building boundary box.*

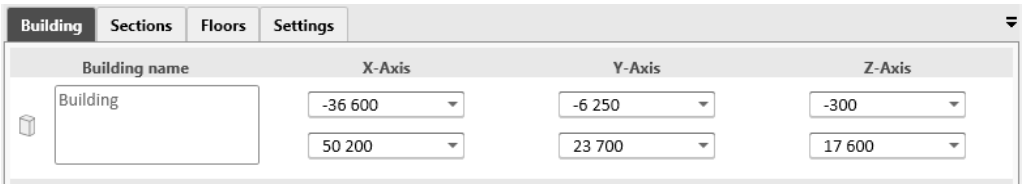


Figure 9.2 *Modified boundary box for including also the engine hall objects outside the gridlines and the elevation lines.*

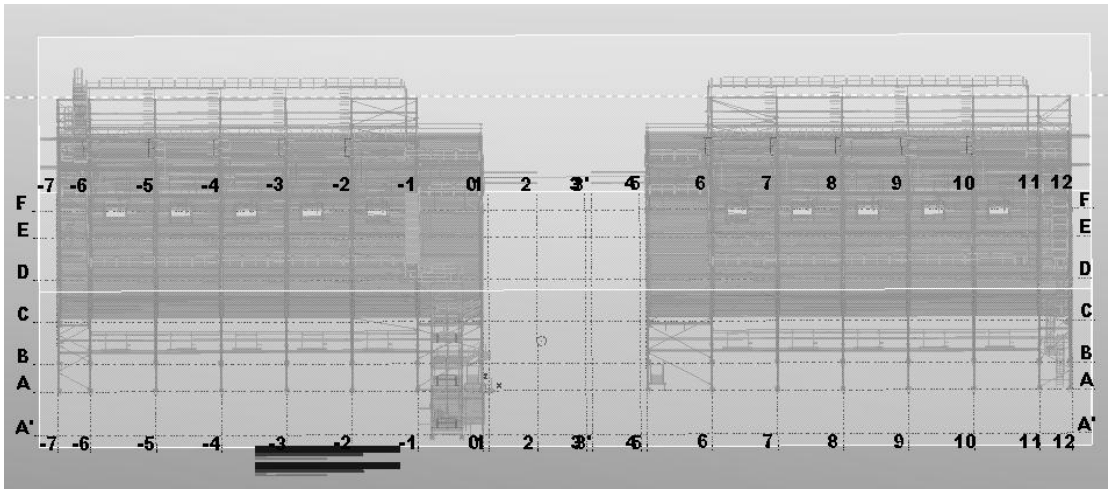


Figure 9.3 *Model view of the boundary box in the building tab.*

3. There are two engine hall modules in our case: Engine hall A and Engine hall B. The building has been divided to 15 sections according to the main column lines. In addition, there is a separate section for the Stair tower. Boundary Boxes has been set big enough so that we can make sure that all the elements are taken in the account. (Figure 9.5) Model view of the boundary boxes in the Sections tab has been presented in Figure 9.4.

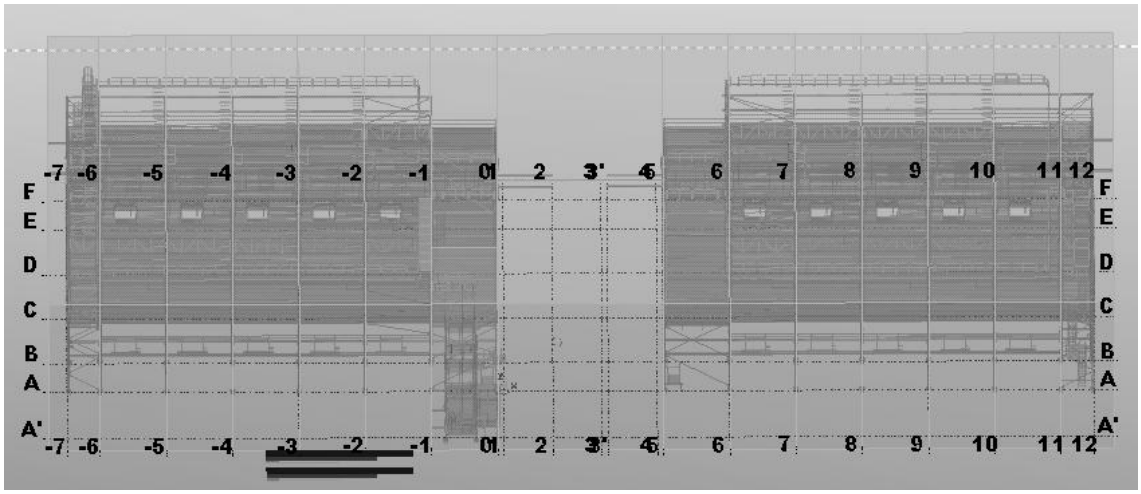


Figure 9.4 *Model view of the boundary boxes in the section tab.*

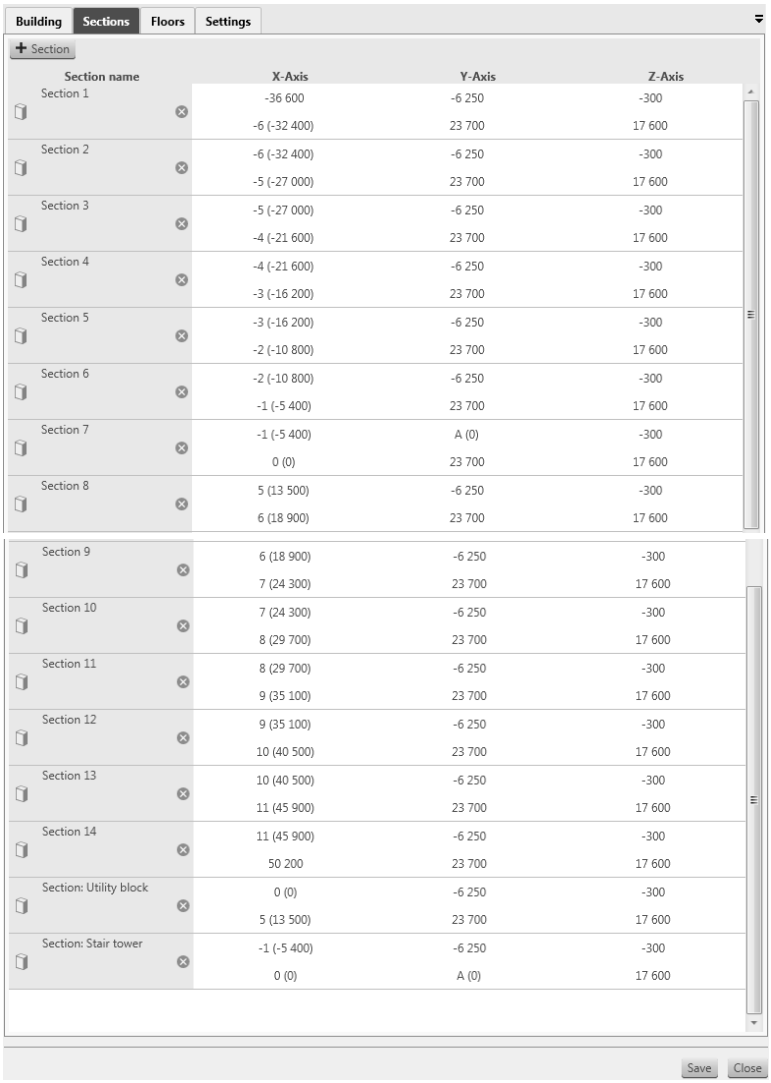


Figure 9.5 *Section tab in the Boundary boxes for locations window.*

4. In “Floors” tab, divide building to floors according to major structural milestones in frame erection (Figure 9.6). In this example, frame has been divided to three floors: Columns, beams and bracings (floor 1), truss structures (floor 2) and radiator structures (floor 3). Choose the boundary elevations so that the objects that are desired to allocate upper floor are fully covered by the upper floor coordinate definition box. Model view of the boundary boxes in the Floors tab has been shown in Figure 9.7.

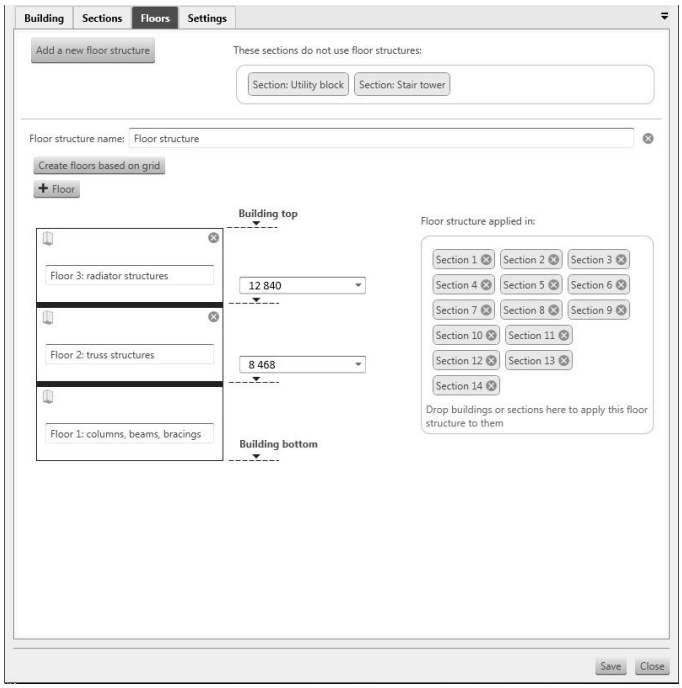


Figure 9.6 *Floor tab in the Boundary boxes for locations window.*

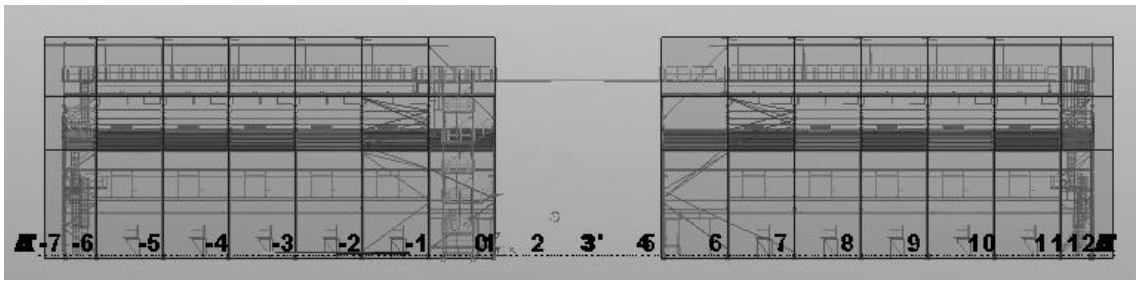
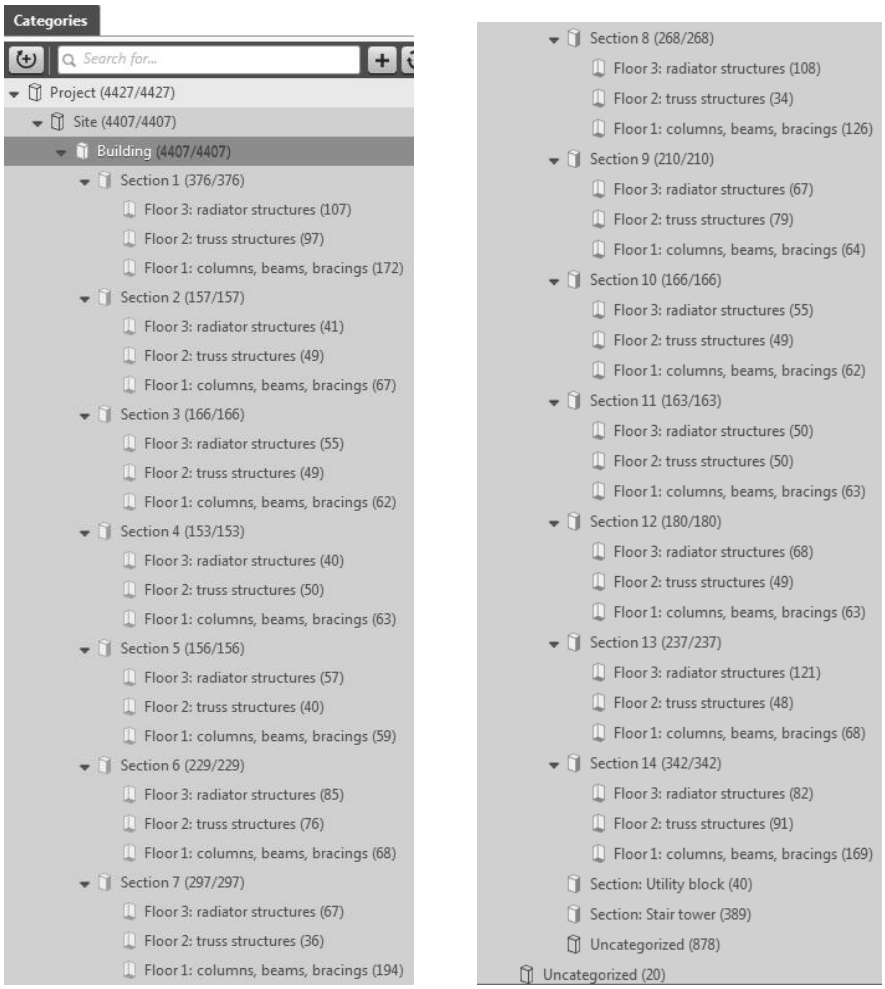


Figure 9.7 *Model view of the boundary box in the Floors tab.*

5. For saving the boundary box definitions, click “Save” icon in the Boundary boxes for locations window. We have now created location categories consisting of sections with floor based subdivision (Figures 9.8 and 9.9).

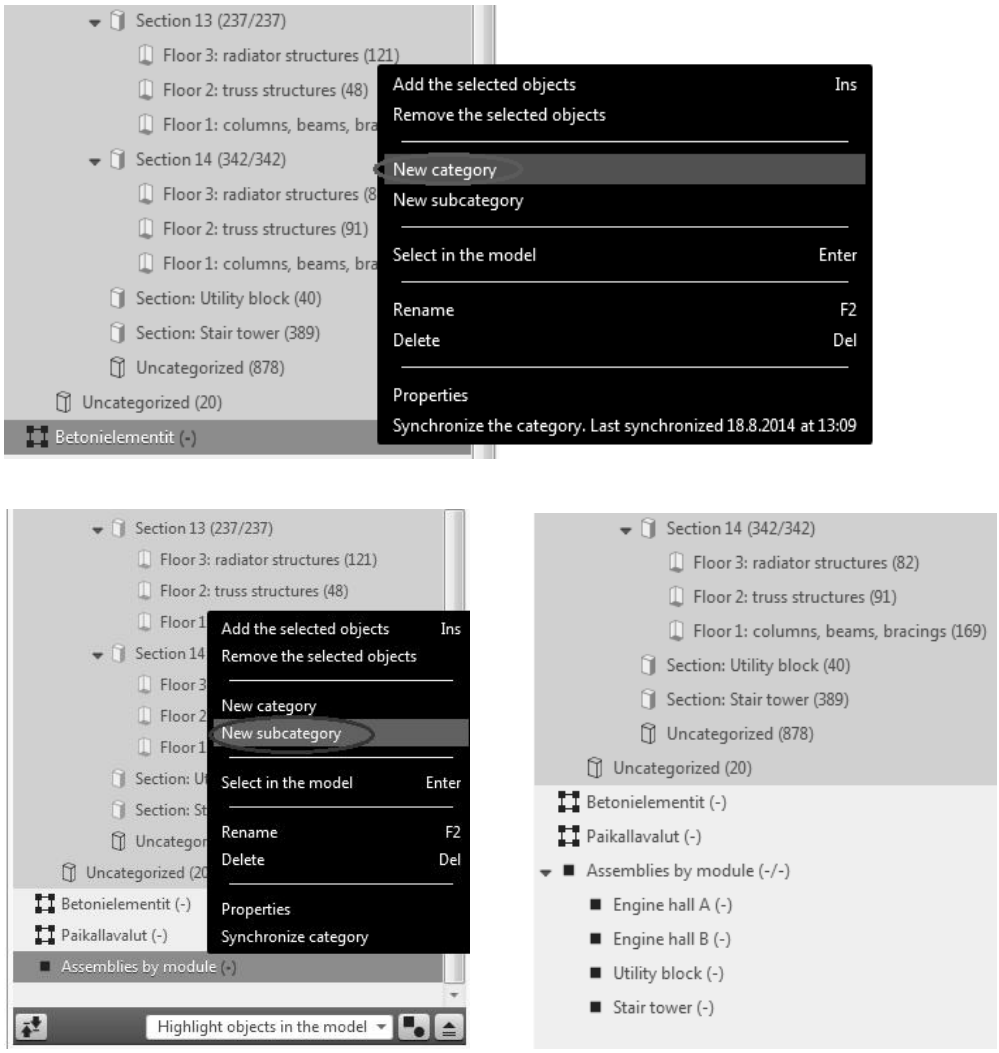


Figures 9.8 and 9.9 *Location categories in the Categories tab.*

9.1.2 Organizer: Creating assemblies by module category

In order to manage assembly data using the Organizer tool we must create a category tree by the modules. In our case, the building has been divided to three different modules: Engine hall A, Engine hall B, Utility block and Stair tower. The same modular division is used in assembly lists.

First create a category in the Categories tab and name it as “Assemblies by module”. This can be implemented by clicking some of the categories existing on default, clicking “New category” and renaming it as “Assemblies by module”. Right click the folder and choose “New subcategory”. In our case, we have named the subfolder as Engine hall A according to the module. Repeat this action so many times that you want to create subcategories for modules. Steps for creating a category tree according to modules has been presented in Figures 9.10, 9.11 and 9.12.



Figures 9.10, 9.11 and 9.12 *Steps to create a category tree according to the modules.*

Objects can be attached to the modules by right clicking the created subcategory and choosing “Properties” The desired sections or floors can be dragged to the filter field from the location category tree. Multiple sections or floors can be chosen by pressing the Ctrl button while choosing the desired rows in the location category tree. In the “Category properties” window activate “Include only assemblies” option. To save the changes, click “Save” icon in the same window. Aforementioned steps has been illustrated in Figure 9.13.

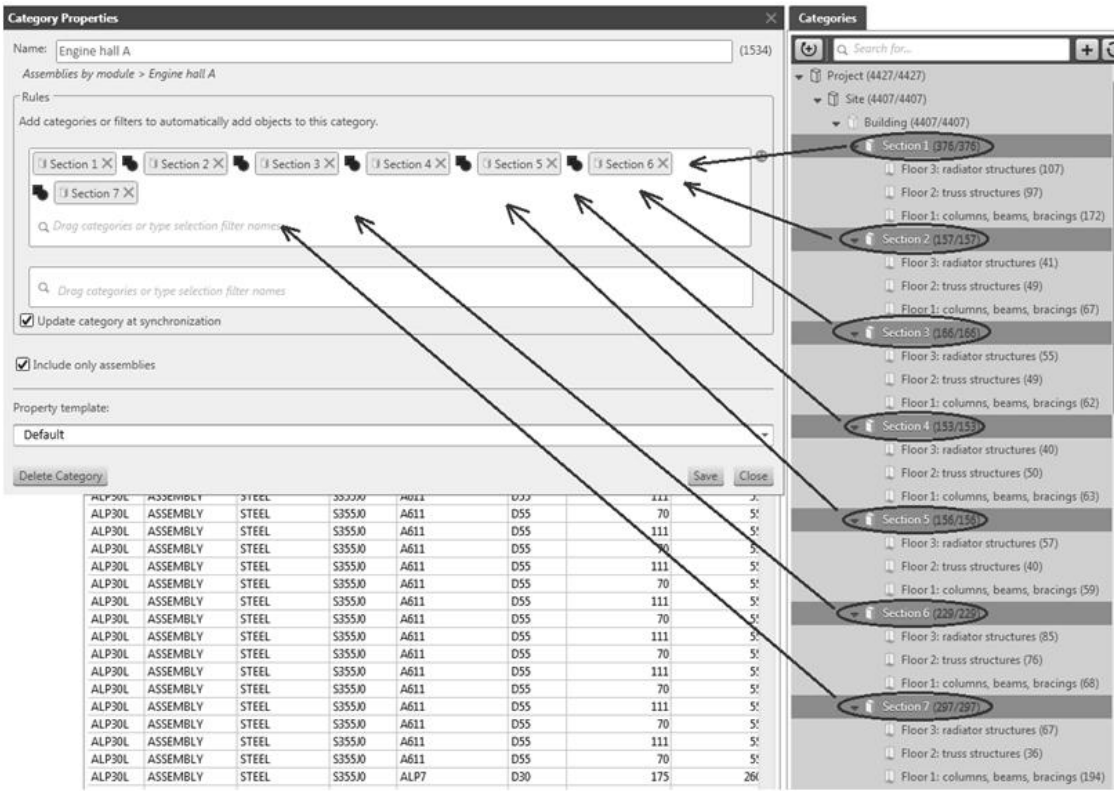


Figure 9.13 *Grouping the sections to module subcategory in "Assemblies by module" category.*

In order to get the made changes visible, synchronize the subcategory by right clicking the subcategory and by clicking "Synchronize the category" (Figure 9.14). Repeat the above-mentioned steps for all the other modular subcategories. You can also synchronize the whole category or the whole model at the same time.

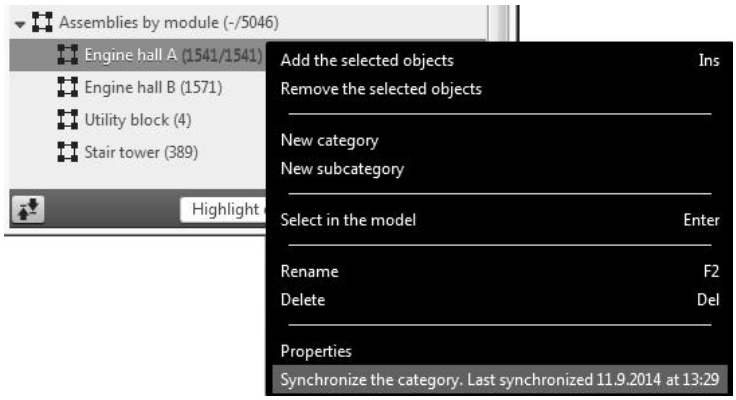


Figure 9.14 *Synchronizing the category or subcategory.*

9.1.3 Organizer and Phase Manager: Dividing model to phases

Phase division is useful when there is a need for section based frame element packing in the project. This system can be used when the installation works must be started from one end of the engine hall. Gridline based installation requirements are usually set by technical issues, such as tight schedule and little laydown area or other free space on the site. Following phase division presented in Figure 9.15 is based on the thinking that the

engine hall installation works are started, for example, from one end of the engine hall and continued to the next section at the same floor. This principle can be used for the floors one and two. Third floor is installed from bottom to top so it is set to be one phase.

Assemblies are divided to phases based on the floor and section division. Phase division is considering all the engine hall modules. One phase is same as a module if only rough phase division is needed.

If more complex phase division is needed it can be easily implemented using volumetric areas bordering model objects. In our example case first and second floors are divided to phases according to the section division. Thus there are 14 phases for both first and second floor. Third floor is divided by modules, so there is one phase in third floor for Engine hall A and one for Engine hall B. Frame elements belonging to the Utility block and the Stair tower are forming their own phases.

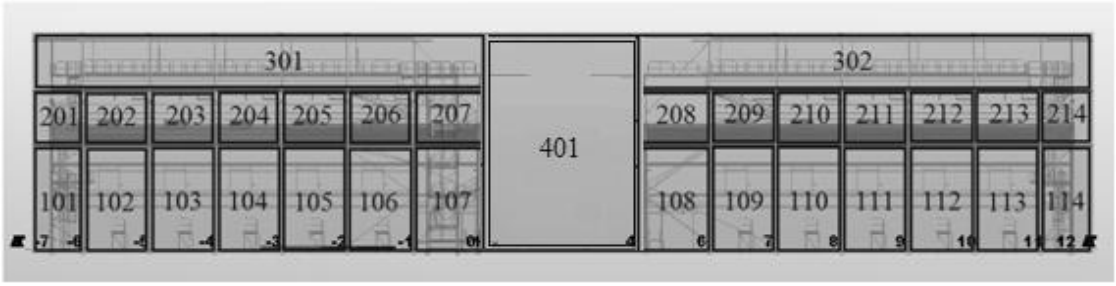


Figure 9.15 *Phase division used in the example case for Engine hall A, Engine hall B and Utility block.*

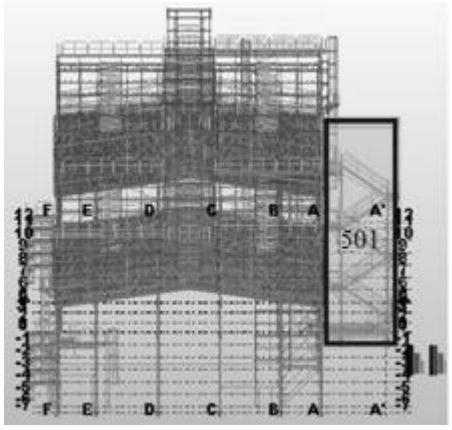


Figure 9.16 *Phase number and physical location for the example case stair tower.*

Frame elements can be packed according to the presented phases if the nature of the project will demand that. Fewer phases are usually needed for managing element packing or installation in the project. Modular phase division is sufficient if there is enough free space in the laydown and installation area. In our case example, this means dividing the engine hall for two engine hall modules, one utility block and one stair tower.

Usually section based packing is required if the project is exceptionally challenging. Installation sequence number based packing instead is better way to pack the elements in a standard project. Although the phase numbers would not be used for managing the

packing they can be used for installation and design management. For example, phase number attached to assemblies will ease to perceive the location of an assembly visually if exported to Tekla BIMsight.

Since the phase division is based on the volumetric areas formulate in the Organizer tool and automatic volumetric grouping of assemblies, phase division can be used even if there is not any visible benefit at the beginning of the project. Some applications for the information may occur later when all the lists are printed out or the structural model is exported to Tekla BIMsight for site management.

Steps for attaching phase number for the model objects are the following:

1. Open Phase Manager tool by clicking “Tools > Phase Manager...” in the toolbar of Tekla Structures. Phases are created by clicking “Add” icon and setting the name and the number for the phase. In our case example we have named the phases according to their module, floor and section. Phases created in the Phase Manager are presented in the Figure 9.17.

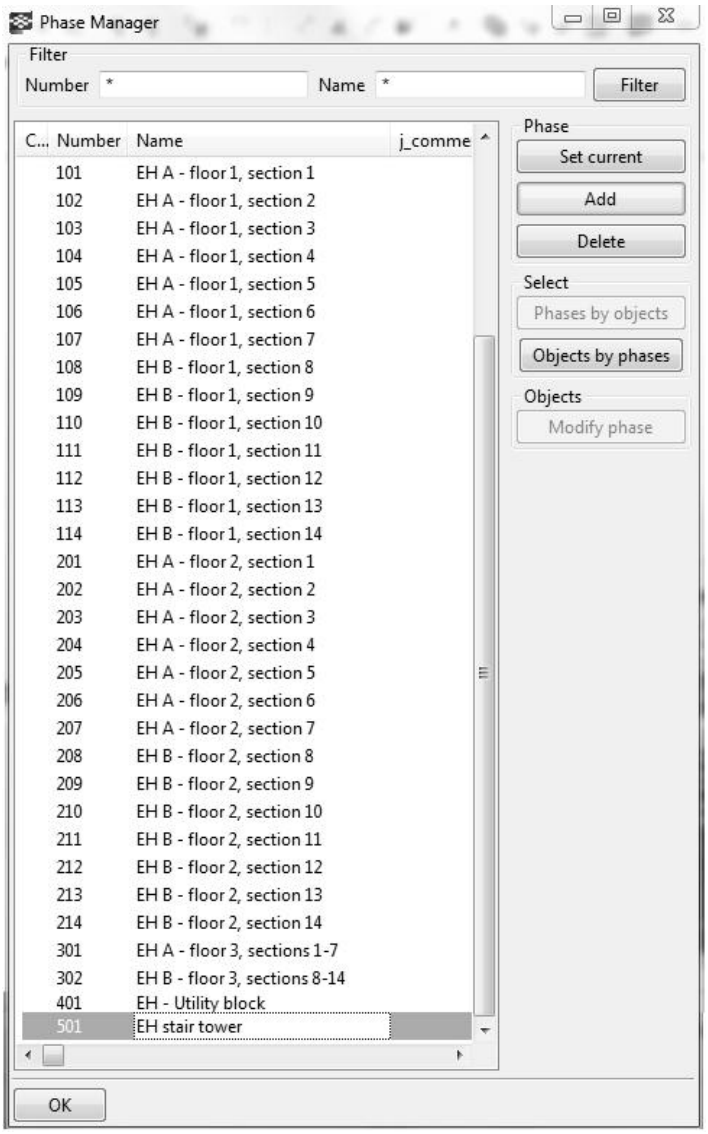
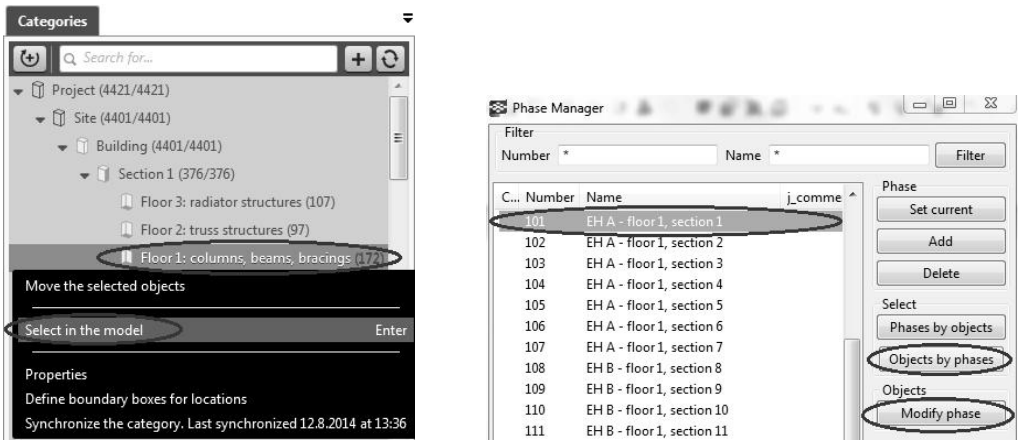


Figure 9.17 *Phases created in the Phase manager tool.*

2. Select location subcategories related to the phase in the Organizer tool. For example, “Floor 1: columns, beams, bracings” subcategory in “Section 1” category is selected by right clicking the subcategory and selecting “Select in the model” (Figure 9.18). After this choose the related phase in the list in of the Phase manager tool, activate “Objects by phases” and click “Modify phase” icon (Figure 9.19). Repeat these actions until you have attached all the subcategories in the Organizer tool to the related phases. Synchronize the Organizer with the model once you are finished.



Figures 9.18 and 9.19 *Steps to attach assemblies in the Organizer to the related phase.*

9.1.4 Organizer: Creating template used for model categorization

Templates can be used as visual tool for managing assemblies and other objects in Object Browser tab in the Organizer tool. Templates can be created by clicking "Open settings" in the Organizer tool (Figure 9.20). You can create a new template by clicking "+Template" icon and both import and export templates as xml files. Created template files are saved inside the ProjectOrganizer folder located in the model folder. These customized template files can then be copied from one project to another. You can also save the property template to the "…\Environments\environment\system\ProjectOrganizerData so that it is available for all models [1.1].

There is always a default template called "Default" in the Settings window. You can use default template or some other template as a layout for a new customized template. You can save the made changes to the activated template by clicking "Keep" icon.

Properties that can be set for the columns are listed on the left side of the Settings window. On right side of the window is presented the Columns with properties that are chosen to be presented in the template. Properties can be dragged from left side list into the selection fields for column properties that are presented on the right section of the window. You can also create your own property by clicking "+Custom" icon. You can either create the property based on the existing ones by choosing "Formula" or customize your own property by choosing "Property". You can add columns by clicking "+" icon and delete them by clicking field specific "x" icon. Aforementioned properties has been illustrated in Figure 9.21.

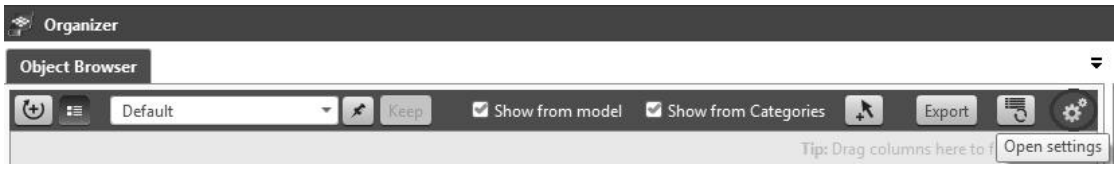


Figure 9.20 *Open settings icon in the Organizer tool.*

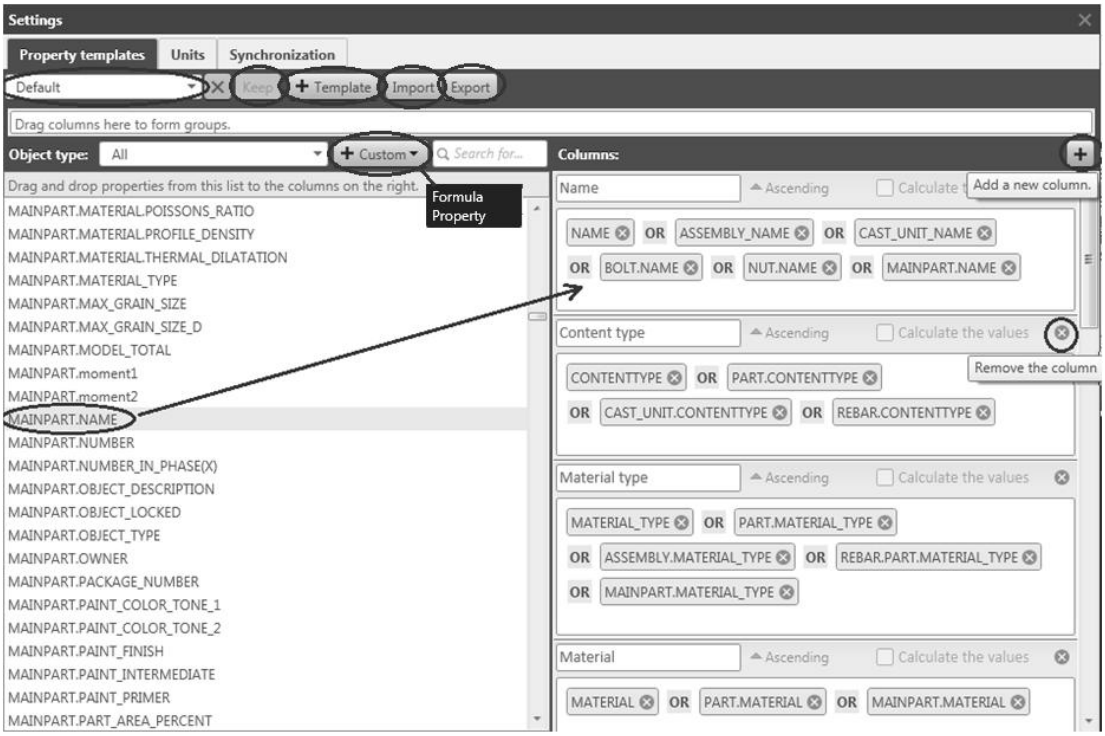


Figure 9.21 *Icons and selection fields in the Settings window: template selection field, icon keeping the made changes in the template, icon for adding a template, icon for importing and exporting the template, icon for creating a custom property by using a formula or property, ion for adding a new column, icon for removing a column, and adding properties to the column field.*

Next we will create a template containing assembly specific installation sequence number, assembly weight and other assembly related data. We have named it as “Assembly list – UDA – Erection code”. Grouping by column properties can be implemented by dragging and dropping the created columns in the selection field on top of the property list. You can formulate many groups and they are arranged hierarchally in the selection field. In our example assemblies are first grouped according to their installation sequence number and then by assembly mark. Aforementioned steps has been presented in Figure 9.22.

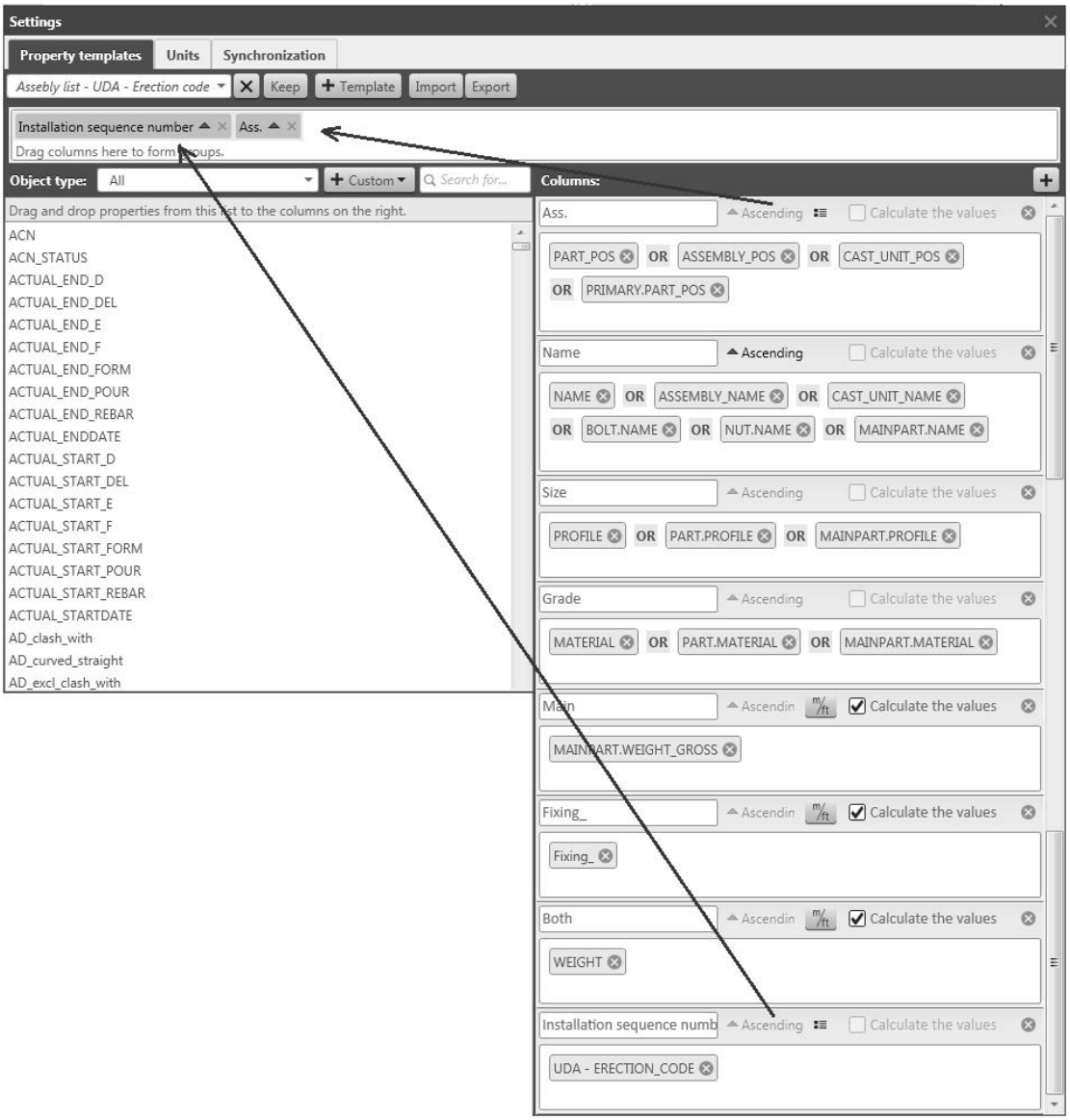


Figure 9.22 *Properties set for "Assembly list – UDA – Erection code" template and grouping according to the property columns.*

"Fixing_" property has been created using the Formula tool. Drag "WEIGHT" property in the "Create Formula" window, click "-" icon and drag and drop "MAIN-PART.WEIGHT_GROSS" property in the window. Unit type has been selected to be "Weight". Customized formula is created by clicking "Create" icon in the field.

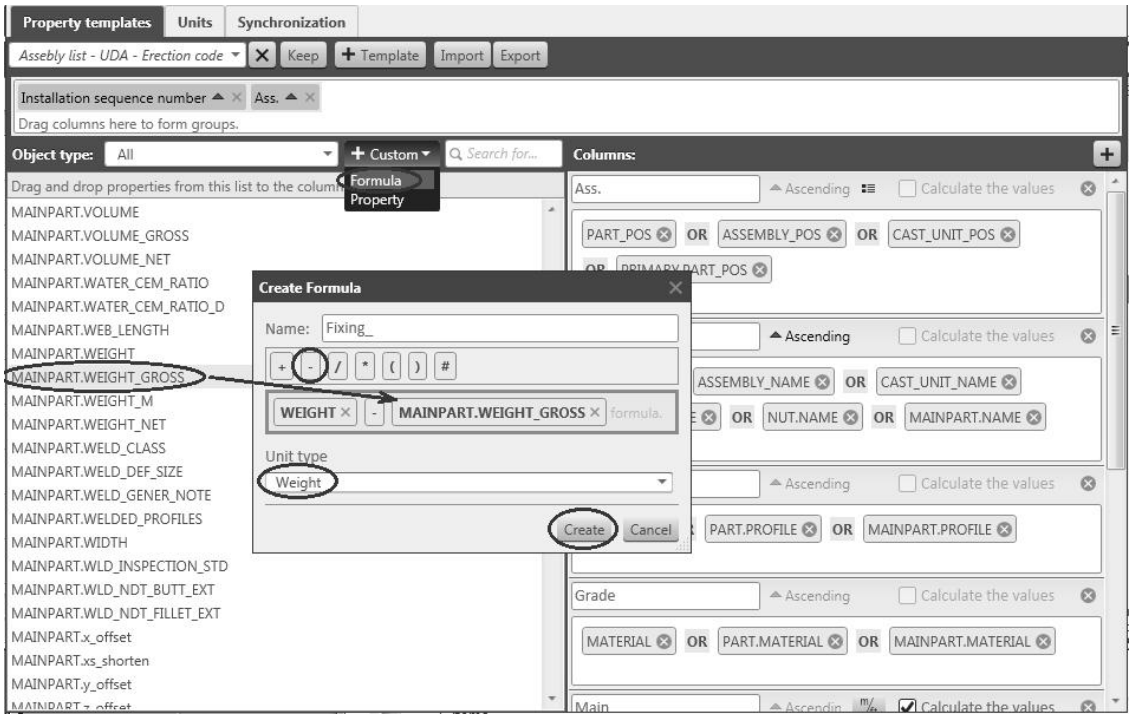


Figure 9.23 *Properties set for "Assembly list – UDA – Erection code" template.*

9.1.5 Organizer: Attaching installation sequence number to the model objects

9.1.5.1 Attaching installation sequence number to assemblies

Installation sequence number can be used for managing both the frame element packing and installation. Installation sequence number will tell the element supplier the right packing order. It will also tell the contractor in a rough level in which order the elements are to be installed. One engine hall module has been divided to five different installation phases expressed using an installation sequence number. Assemblies have been attached to these groups using the following division:

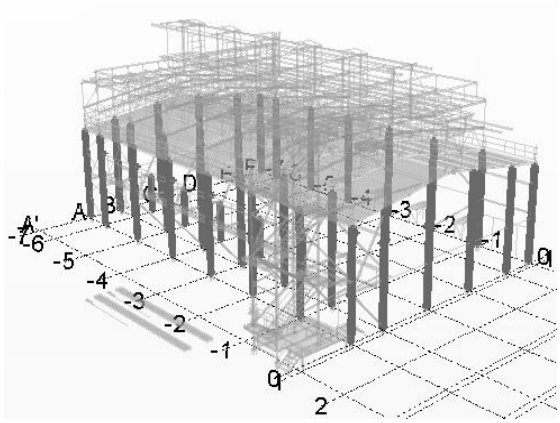


Figure 9.24 *Installation sequence number 1: Main columns.*

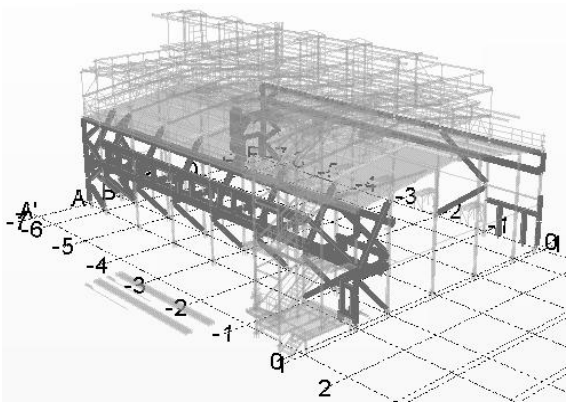


Figure 9.25 *Installation sequence number 2: Bracings, lower support beams, crane beams, crane platforms, door second beams and door platforms.*

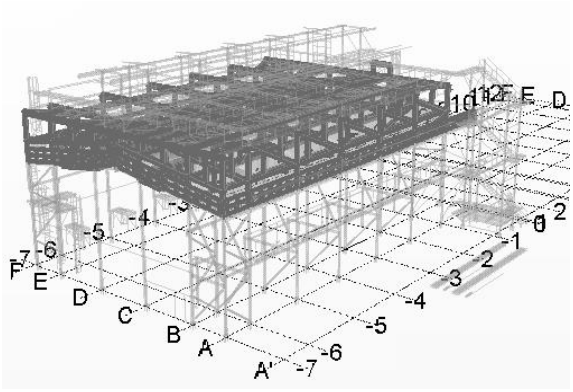


Figure 9.26 *Installation sequence number 3: Roof trusses, roof second beams and inlet support beams.*

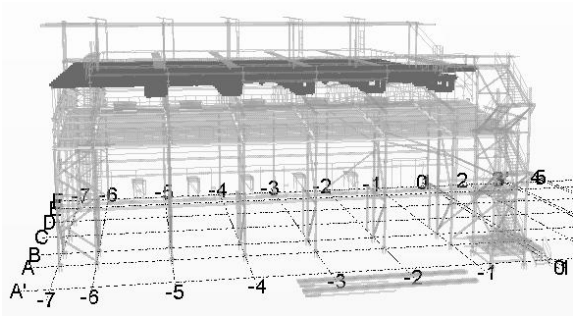


Figure 9.27 *Installation sequence number 4: Lower support beams for radiator structures and support beams for cooling pipes.*

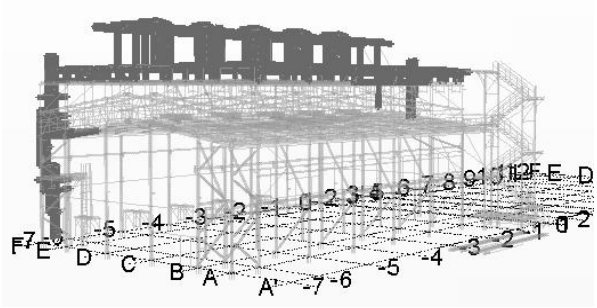


Figure 9.28 *Installation sequence number 5: Upright beams for radiator structures, horizontal beams for radiator structures and platforms, platforms, ladders, and crane beams with related support beams.*

In our case project we have a Utility block module between the Engine hall modules and the total frame weight of it is 54 tons. There can also be other rooms between engine hall modes and weight of these modules is usually smaller, about 20 tons. Although Utility Block could be divided to separate installation sequences, other and more commonly used module types are usually much lighter and it is practical to use the same system regardless the module type.

The total weight of the case Stair tower is 7.3 tons and less than maximum weight of one container (20 tons). Therefore hanling the stair tower as a one installation sequence is sufficient division for the management of packing.

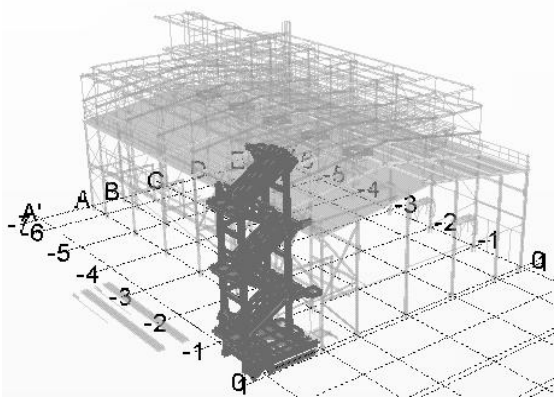


Figure 9.29 *Installation sequence number 1: Stair tower: columns, bracings, beams, stairs, platforms and other stair frame elements.*

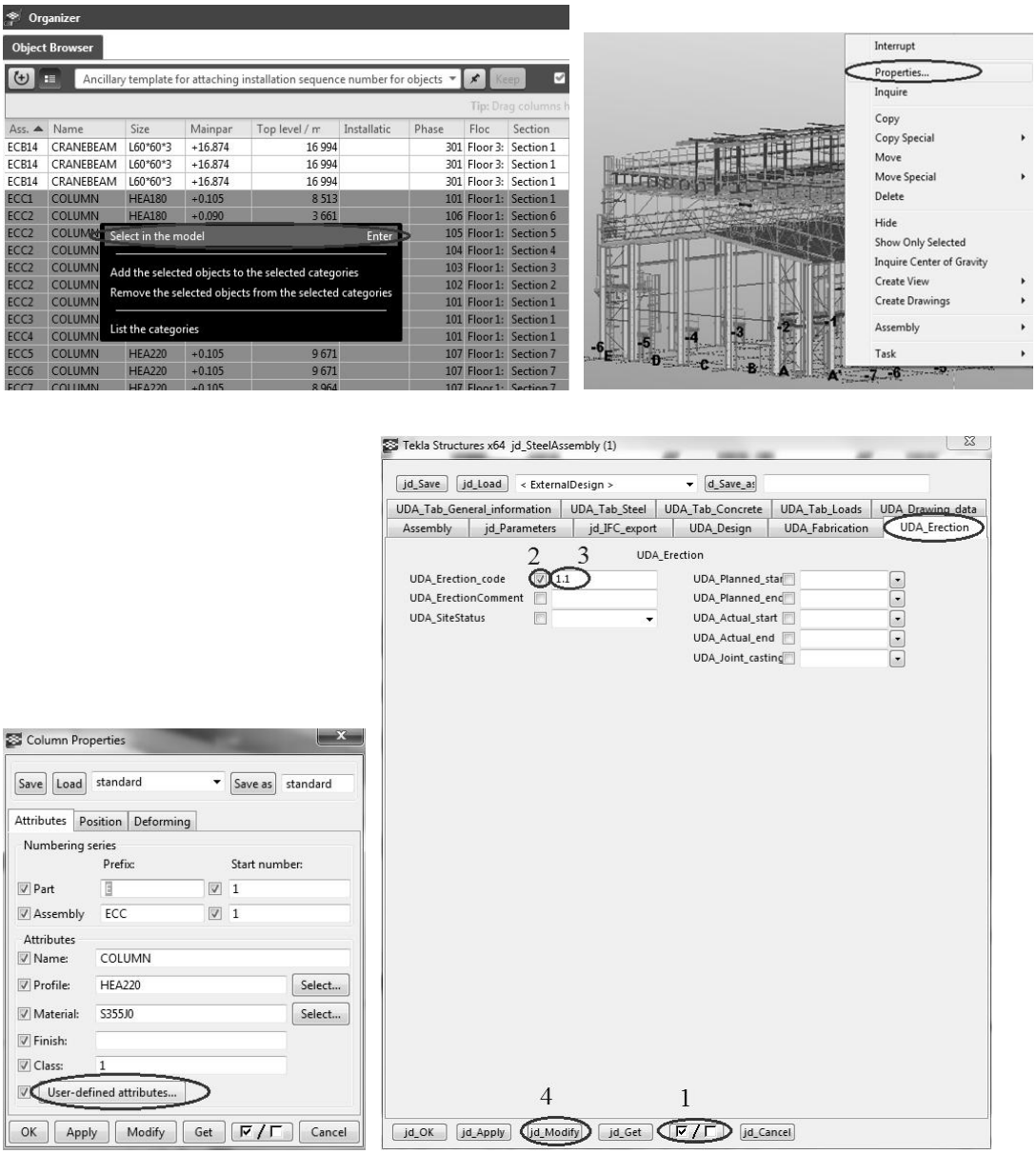
In our case, the numbers haven't been attached to the objects in the modeling phase, so numbers must be attached to the objects afterward using the Organizer tool. You can use ancillary templates in the Organizer for managing this attaching work. In our case example we have used template that includes the columns for main part bottom and top level. You can also search in the uncategorized groups for finding the assemblies that are not yet attached to any installation sequence. You can also use View Filter for easing the attaching work.

These steps are not needed if the numbers have been set in the early modeling stage. They can be set for the assemblies simultaneously with the Assembly prefix, Class and other assembly related attributes.

Module specific intallation sequence number marking system can be implemented in multiple ways. In our case case, installation sequence numbers for the engine hall A would be 1.1 – 1.5 and for the engine hall B 2.1 – 2.5. Installation sequence number for the Utility block is 3.1 and for the stair tower 4.1.

For attaching installation sequence numbers to objects afterwards, select all the desired objects in the Organizer using Ctrl and Shift buttons or using View Filter. In the following example, all the main columns of Engine hall A are selected in the Organizer. After that right click the painted raws and select "Select in the model". Now the selected asseblies (objects) are selected in the model view. Right click one of the objects and select "Properties…". Choose the "User-defined attributes…" icon and "UDA_Erection tab in the pop uped window. In the the case of columns, Enter value 1.1 (engine hall A,

installation sequence number 1 => 1.1) in the field “UDA_Erection_code”. Remember to deactivate all the other fields than “UDA_Erection_code” so that you won’t change other attributes of the assemblies. Then click “jd_Modify” icon and “jd_OK” to save the made changes.



Figures 9.30, 9.31, 9.32 and 9.33 *Steps to attach installation sequence number for the model assemblies.*

All the other installation sequence numbers are also attached to the related objects using the same method. To get the installation sequence numbers visible in the Organizer we must syncronize it with the model. In this case, click “Synhronize with the model” icon in the Categories tab.

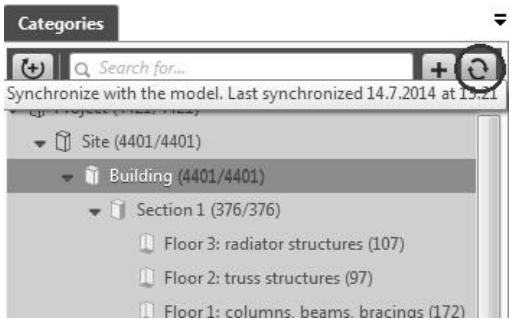


Figure 9.34 "*Synchronize with the model" icon in the Categories tab of the Organizer.*

9.1.5.2 Attaching installation sequence number to parts

At the moment it is not possible to visualize erection order related to user defined attributes attached to the assemblies in Tekla BIMsight. User defined attributes attached to model parts instead can be visualized in BIMsight. Therefore we will next attach installation sequence numbers to model parts using the Organizer tool for grouping main parts. This can be done after the installation sequence numbers have been attached to the related assemblies. Same work can also be implemented using both the Organizer and View Filter, or View Filter alone.

Steps to attach the installation sequence numbers for the main parts are the following:

1. Open the formerly created template containing the installation sequence numbers in the Organizer tool. In our case, the template has been named as "Assembly list – UDA – Erection code" and the module we are dealing with is called Engine hall A. Right click the module in the Categories tab and click "Create a three by property". Choose then "UDA - ERECTION_CODE" property for the value. Now we have created a property three of the installation sequence numbers. Set property template as "Default" for all the sequence number rows in the category three. This can be executed by, for example, right clicking row 1.1, choosing "Properties" and setting the property template. Remember to deactivate all the other fields than "UDA_Erection_code" so that you won't change other attributes of the selected parts.

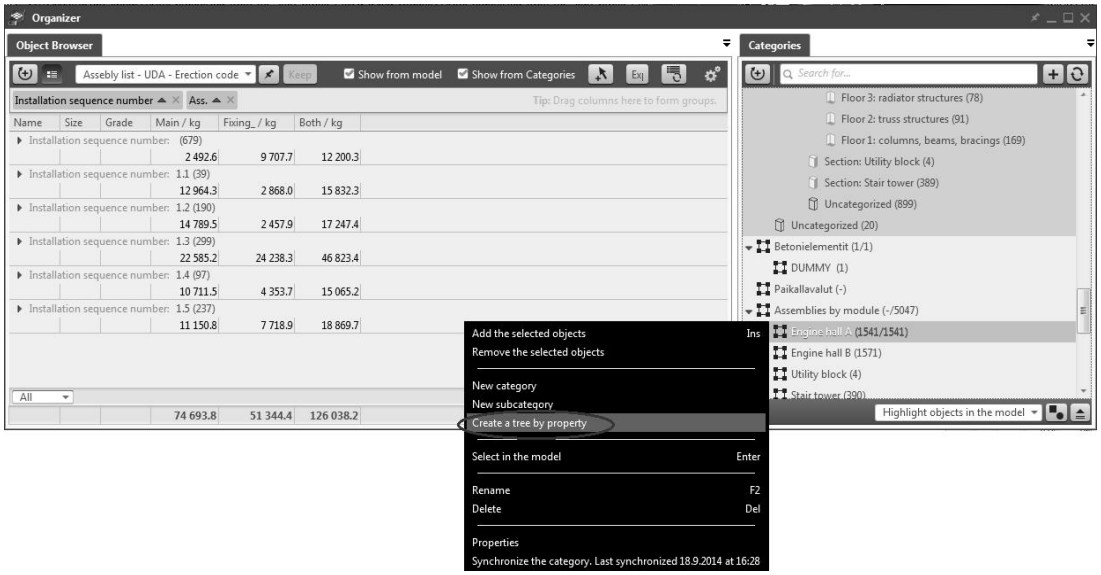


Figure 9.35 *Creating a tree by installation sequence number for assembly category "Engine hall A".*

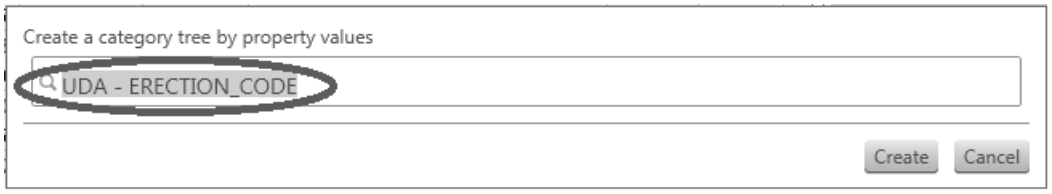
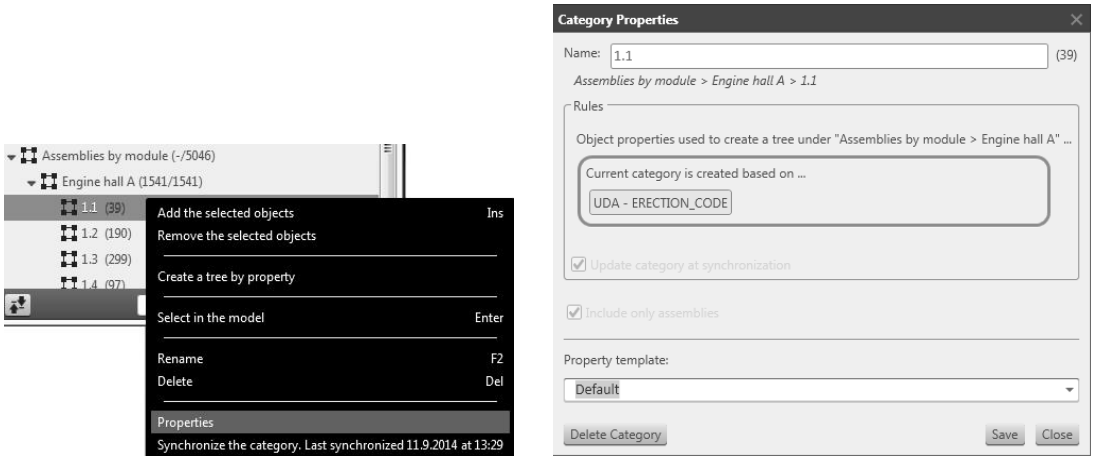


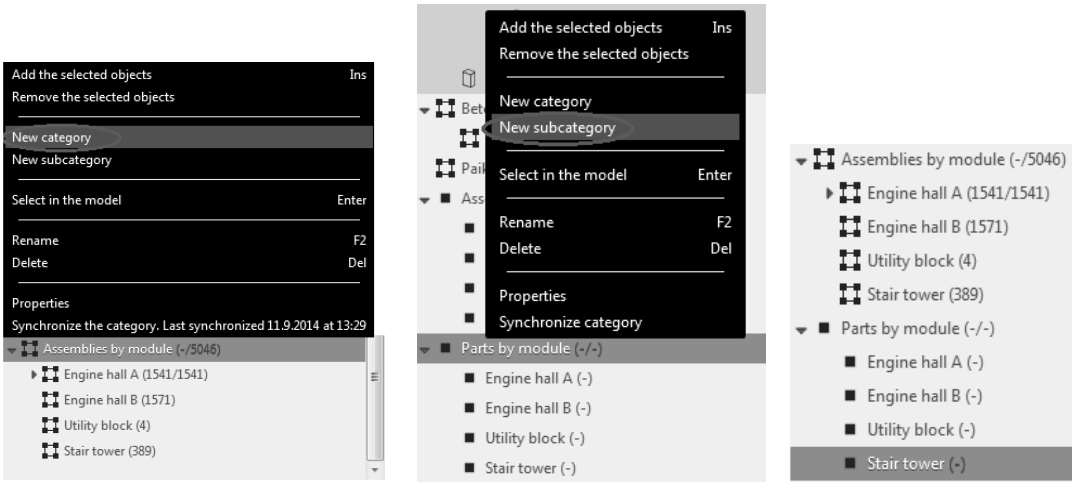
Figure 9.36 *Set property value for the category tree.*



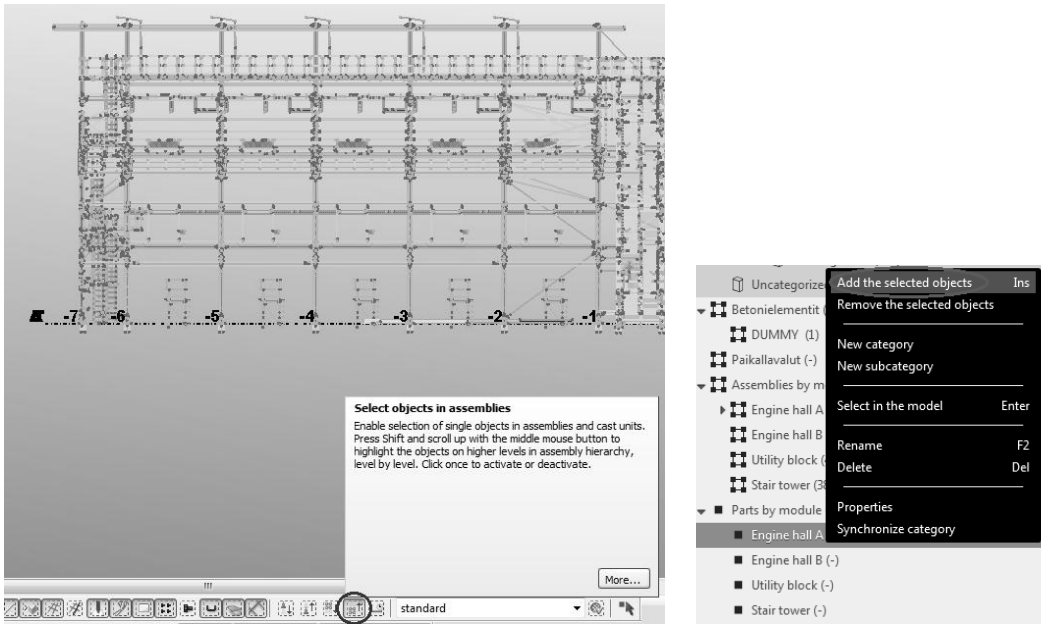
Figures 9.37 and 9.38 *Steps to set property template for installation sequence number subcategories.*

2. As we can see, there is quite small number of objects available in the Categories tab. This is because only assemblies are listed in the tab, not any main parts or other parts. In order to get parts visible in the Organizer tool we must manually select the parts in the model view and make a separate category for them. In our case we have created a category called "Parts by module" and three subcategories "Engine hall A", "Engine hall B", "Utility block" and "Stair tower" under it. In order to get assemblies visible in the organizer you must activate "Select objects in assemblies" selection icon and choose the model objects. Choose the

parts, for example, for engine hall A, right click the related subcategory and choose “Add the selected objects”.



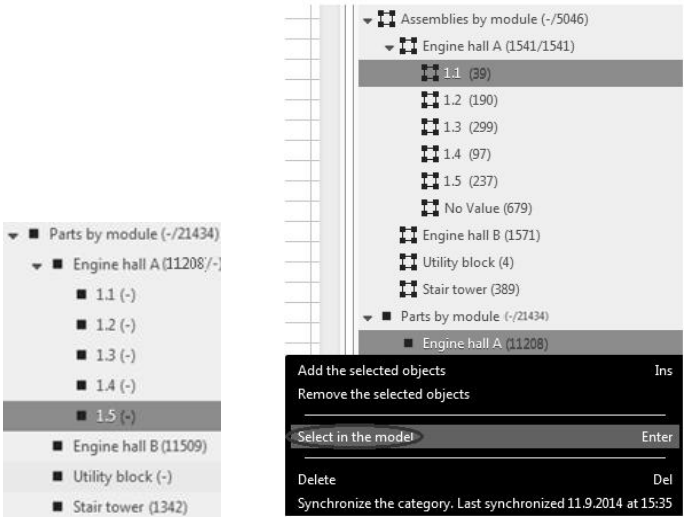
Figures 9.39, 9.40 and 9.41 *Steps to create “Parts by module” category with module based subcategories.*



Figures 9.42 and 9.43 *Steps to attach model parts to the related modular subcategories.*

3. Now we have added selected parts to the related category. We can make new subcategories to the newly created subcategories. In our case, we will create subcategories 1.1 – 1.5 for Engine hall A, subcategories 2.1 – 2.5 for Engine hall B and subcategory 3.1 for Utility block and 4.1 for Stair tower. We can select the installation sequence related parts by using “union” function between the select assembly subcategories in the “Assemblies by module” category and module subcategories in “Parts by module” category. For example, both subcategory 1.1 in Engine hall A of “Objects by module” category and subcategory “Engine hall A” of “Parts by module” category can be activated using Ctrl button. You must first select part based subcategory and then assembly based subcategory.

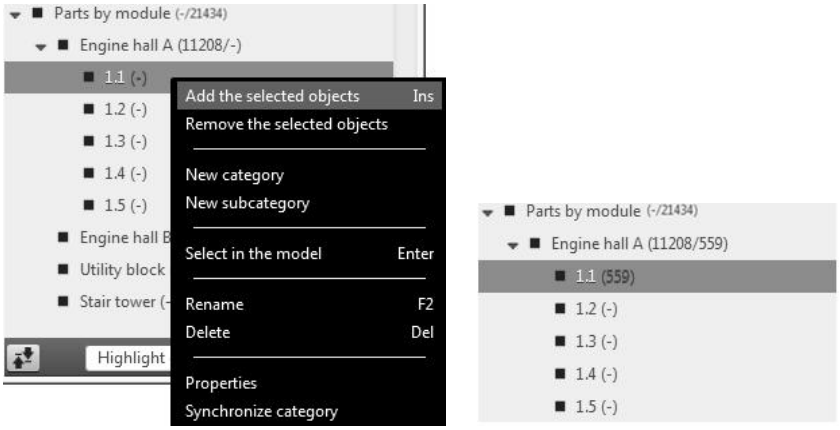
Then right click one of the two selected subcategories and choose “Select in the model”. This action will activate all the parts belonging to the assemblies under the subcategory 1.1. Same parts are also presented in the model view.



Figures 9.44 and 9.45 *Steps to create installation sequence number based subcategories under the modular subcategories and to select installation sequence number related objects using the “union” function.*

Figure 9.46 *Selected parts in the case model view.*

4. Right click subcategory 1.1 in Engine hall A inside “Parts by module” category. Choose “Add the selected objects”. Repeat the same steps to the all the other subcategories inside “Parts by module” category.



Figures 9.47 and 9.48 *Adding the selected parts into the installation sequence number based subcategories in the “Parts by module” category.*

5. Now we have attached all the parts to the assembly related installation sequence number groups. Next we will attach installation sequence numbers similar to the related assemblies to all parts. Right click subcategory 1.1 in “Engine hall A” subcategory inside “Parts by module” category and choose “Select in the model”. Click then “Edit > Properties…” in the model tool bar. Click then “User-defined attributes…” icon and insert number “1.1” in the field “UDA_Erection_code” in the “UDA_Erection tab”. Then click “Modify” icon in the “User defined attributes…” window. Do not repeat the modify command in the “Column properties” window to avoid modifying part profile settings. Repeat attaching the installation sequence number expressed in UDA_Erection_code field for all the other parts of the model.

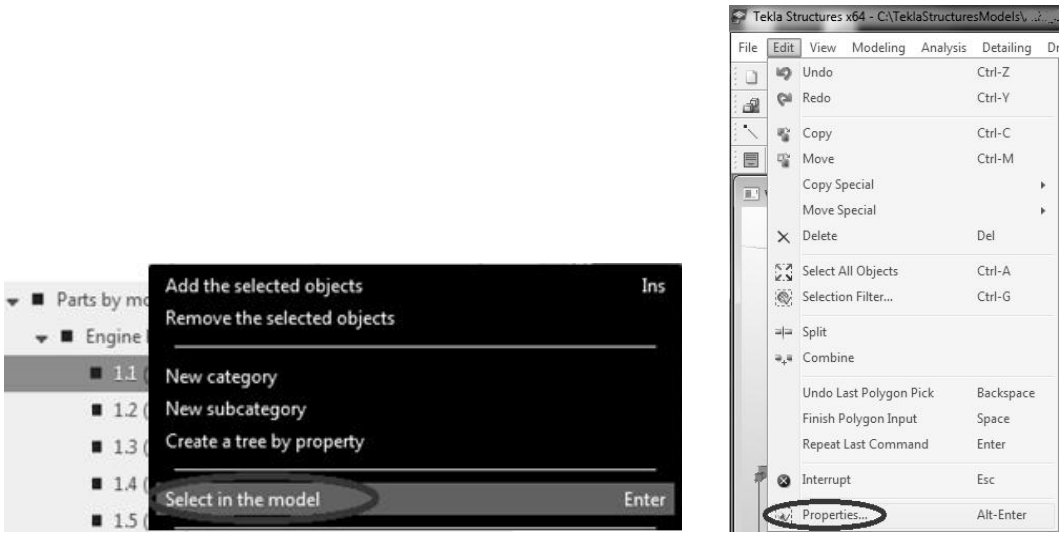


Figure 9.49 and 9.50 *Selecting parts under the subcategory for modifying part properties.*

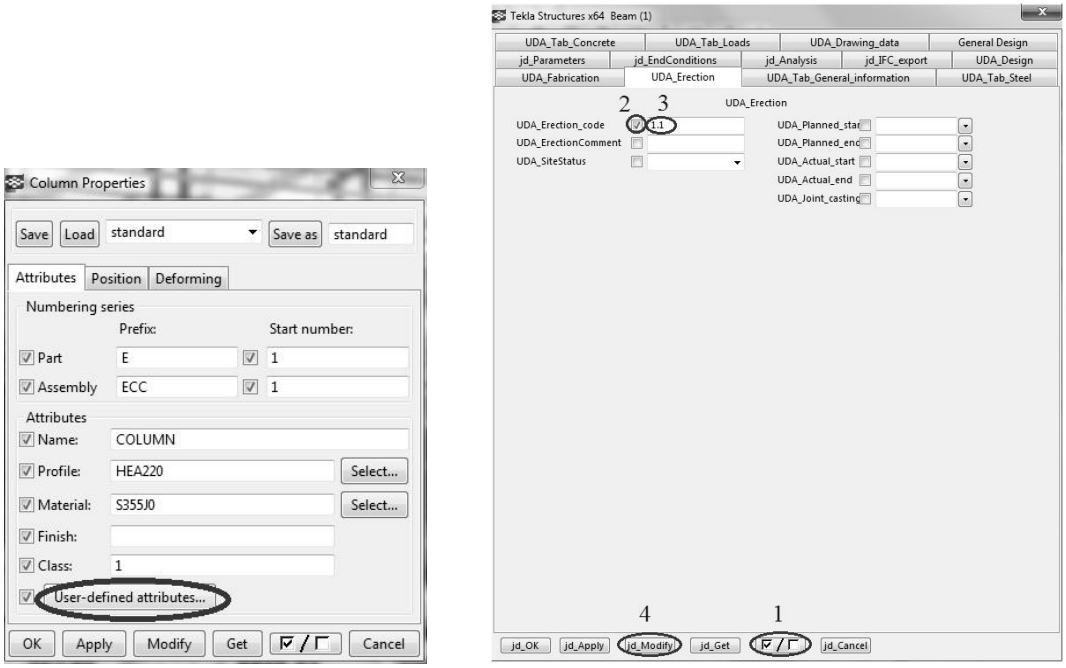


Figure 9.51 and 9.52 *Setting installation sequence number to parts by inserting UDA_Erection_code.*

9.1.6 Lotting Engine hall assemblies

There are quite large numbers of elements to be delivered at the site and the size and type of the elements are varying a lot. On the other hand, it is practical to pack the containers as full as possible since the intercontinental delivery costs have a significant role in the project budget. The frame element supplier is the one who knows the way of practical element packing and which elements can be packed together. Therefore planning the lotting, in other words planning how the elements are packed inside containers is assigned for the element supplier and it is reasonable to keep it that way. Only installation sequence number is provided for the supplier so that they can pack the elements accordant the installation sequence.

First we will take a closer look at the principle according to which the engine hall elements have been divided to installation sequences. Then we will introduce the tools in Tekla Structures for managing lotting information. Lotting tools for Tekla Structures are introduced not for managing actual lotting work in the workshop but for easing to perceive the weight of different element groups by Structural Designers and Project Engineers. This information can be used for planning the frame erection as well as for planning the packing requirements set for the frame element supplier.

Lotting in the Organizer tool is relatively easy. You can group and organize objects in multiple ways using categories, subcategories and property templates. You can both choose multiple groups at the same time and survey so called empty groups containing objects that have not been attached to any lot group. All these objects can be surveyed visually in the model view when selecting them in the Organizer.

Next we will introduce methods of preliminary planning of lotting by the constructor. Element assemblies can be lotted using the Lotting tool found in Tekla Structures. Other option is to arrange and group assemblies in the Organizer tool in order to have a perception of the total weight and other measurements of the element group. Lotting number can also be written in the assemblies and parts of the model using lotting related UDA numbers. All of these lotting tools can only be used by structural designers. The created lotting information can also be used by both Site Supervisors and Project Engineers if it is defined as UDA attribute for parts and assemblies. In this case lotting information can be imported to Tekla BIMsight by exporting the model with the lotting attributes as IFC model.

Frame elements are usually packed in the size 40’ open top containers. The payload of the typical container is usually 25 – 26 tons, but the maximum net weight of a lot determined by the cranes and other lifter equipments is usually set to be 20 000 kilograms. Tare weight of one 12.2 meters long (40’) open top container is 4300 kilograms. Typical exterior measurements for this type of containers are 12.2 meters (length), 2.44 meters (width) and 2.59 or 2.9 meters (height). [13]

40' DC (dry cargo)

Interior dimensions	Length 12 010 mm	Width 2 330 mm	Height 2 370 mm
Exterior dimensions	Length 12 200 mm	Width 2 440 mm	Height 2 590 mm
Surface area	28,1 m2		
Cubic capacity	66,4 m3		
Payload (new units)	26 000 kg		
Tare weight	4 000 kg		
Euro pallets (120 x 80)	23 units		
Door opening	Width 2 330 mm	Height 2 260 mm	

40'OT (open top)

Interior dimensions	Length 12 015 mm	Width 2 340 mm	Height 2 320-80 mm
Exterior dimensions	Length 22 200 mm	Width 2 440 mm	Height 2 590 mm
Surface area	28,1 m2		
Cubic capacity	64 m3		
Payload (new units)	26 000 kg		
Tare weight	4 300 kg		
Euro pallets (120 x 80)	29 units		
Door opening	Width 2 330 mm	Height 2 260 mm	
Roof opening	Length ca. 11 720 mm	Width ca. 2 205 mm	

Figure 9.53 *Measurements, weight and capacity of typical dry cargo and an open top container [13].*

9.1.6.1 Principles of grouping the objects for installation sequences based on the lot size

In previous chapters we grouped the objects belonging to Engine hall A module according to the installation sequence number. There are five installation sequence number groups of which the group of trusses is the heaviest one. The non sequenctical group is also quite heavy, but it contains elements and parts that are not belonging to the frame element delivery or the elements that are located in the same model but not belonging to the engine hall.

There are five installation sequence groups in our case example and the overall weight of one group mainly varies between 15.1 tons and 18.9 tons. For example, the total weight of the elements belonging to the installation sequence number group 1.1 is about 16 tons. Even though this weight goes under the maximum weight of 20 tons the installation sequence number group can't be used directly as a container lotting group or the whole content inside a container. The presented group weights apply only for the engine hall module of five engines. If the engine hall differs is a couple of more or less, or size of the elements is different, the presented groups sizes don't apply. On the other hand, containers must be packed full which usually means 16 – 18 tons payload of the container according to the supplier.

Total weight of the elements belonging to installation sequence group 1.3 (truss structures) is 46.8 tons. This is a lot more than the weight of other groups and highly exceeds payload of one container. These elements need to be packed in three to four different containers.

In most cases there is enough laydown area on the site for unpacking these containers.

If only a couple of containers can be unloaded simultaneously, elements of installation sequence group 1.3 can be divided to subgroups using project specific system. One option is to divide elements for three gridline sections each of which weight is less than 20 tons. Subgroup division can be expressed in assembly list, for example, as numbers 1.3.1, 1.3.2 and 1.3.3. Elements belonging to the subgroup 1.3.1 are packed first and then element belonging to the group 1.3.2 and so on.

The idea of installation sequence group division is that the containers would be packed continuously. In practice this means that the some of the elements belonging to the installation sequence group 1.2 must be used for filling rest of the container containing elements of the installation sequence group 1.1. Using the same logic, elements belonging to the installation sequence number 1.3 are used for filling rest of the empty space that is left from packing the elements belonging to the installation sequence group 1.2, and so on. In general it is practical to first set the elements, if large in size, belonging in the early stage installation sequence at the bottom of the contaner since they are installed first. This is because it is not reasonable to take a risk that all of the early stage elements can't be filled in the same container.

Benefit of the chosen group size is that in most cases there is no more than two installation sequence groups used for filling one container. Other benefit of the selected group size and division is that the elements belonging to one group are quite homogenous in shape and size. There are mainly two to four main size and shape groups within one installation sequence group, and majority of the content of one container is consisting of these elements.

It is also easier for the element supplier to manage element manufacturing and packing when using aforementioned group division. Due to the workshop management related issues elements are usually manufactured and packed in the groups containing same kind of elements. The presented packing procedure would also prevent too many elements that are not yet istalled to be dragged out of the container and filling the laydown or the installation area with these elements.

On the other hand, the packing is easier to execute if there is both light and heavy groups involved. The heavy groups are mainly consisting of the heavy elements packed at the bottom of the container. Groups consisting of lighter elements can be used for filling the contaners containing the elements belonging to the hevier groups. This will enable maximizing the filling rate of the containers. For example, bracing can be used for filling the containers packed with the columns. Truss structures are containing both large and small elemement so the container can be filled using only the element belonging to this installation sequence.

The containers are only fully filled with frame elements what it comes to the weight, not volume. Usually only half to 2/3 of the volume is required depending on the measeurements of the elements in order to achieve the the maximum payload of a container. The main priciple is that the more geometrically unite and simple the elements are the less volume is needed for packing them.

You can also check in the Organizer if some of the objects are not attached to any of these groups. There is a separate group (so called empty group) for the objects that are not belonging to any of these installation sequence number groups in the Organizer tool. By clicking this group you see these objects in the model view, select them and attach them to some of the created groups.

It can be hard to locate some of the objects to any of the installation groups since it can be hard to estimate in which installation phase they are to be installed. These objects can be set to locate in the containers that are planned to be opened first. This will ensure that no parts are missing when needed.

There can be only small amount of these kind of objects: if there is too many non-sequentically numbered objects, the point of the installation sequence number based system is lost. On the other hand, this non sequentical group can be set to contain elements not belonging to the delivery provided by the frame element supplier. In this case the groupping can be used as a filter for the model contanining all the structural parts needed for the building.

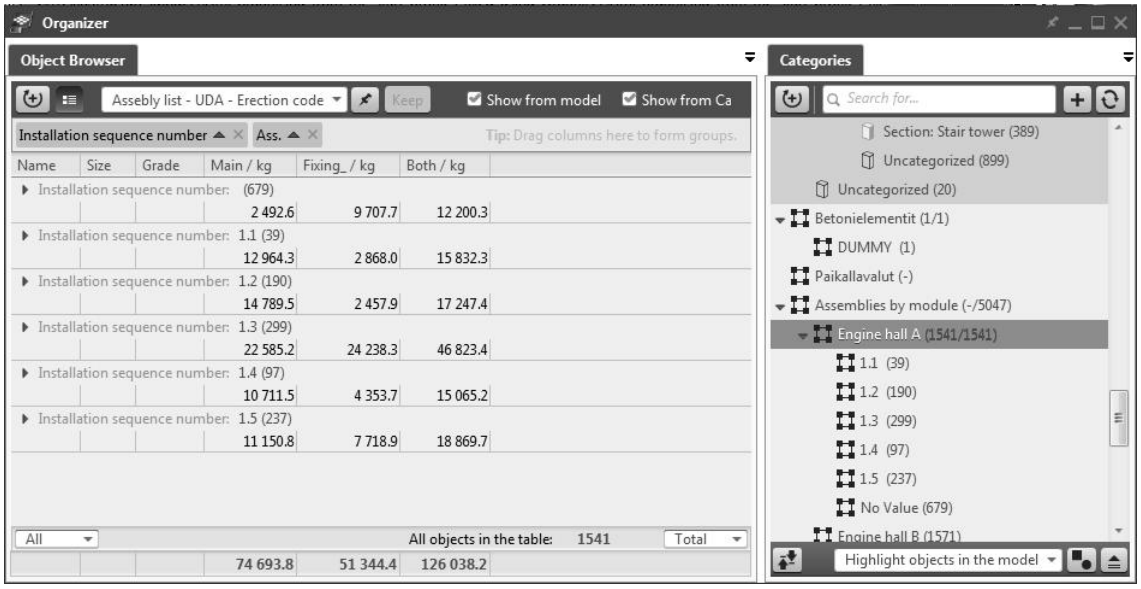


Figure 9.54 *Installation sequence number based grouping for Engine hall A module in the Organizer tool.*

9.1.6.2 Lotting tool

Lotting tool can be used for attaching a lotting number for the model objects. It can be opened by clicking “Tools > Lotting…” in the toolbar. Click “Properties…” icon in the Lotting window. This will open Lot Properties window. Lots can be added, modified and deleted in this window. Insert the desired lot number in the Number field and Lot name in the empty field. In our example we will add number 1 and name “Lot for columns”. Maximum weight in “Max weight” field is set for 20 000 kilos according to the maximum payload of Wärtsilä’s containers. Click “Add” icon to create a lot.

The created lot is visible in both Lot Properties and Lotting window. To add objects in the lot choose the desired objects by pressing Shift button and selecting the objects in

the model view, or select the desired objects using the Organizer tool. “Current values” field in the Lotting window presents the total weight of the selected elements. Click then “Apply selected” in the Lotting window. This will add the selected objects and the total weight of the objects in the “Applied values” field. There is also “Weight left” sub-field in both of the field indicating the weight that is left of the tolerated maximum weight of 20 000 kilograms. Objects chosen in a lot are highlighted once you click the lot group in the Lotting window.

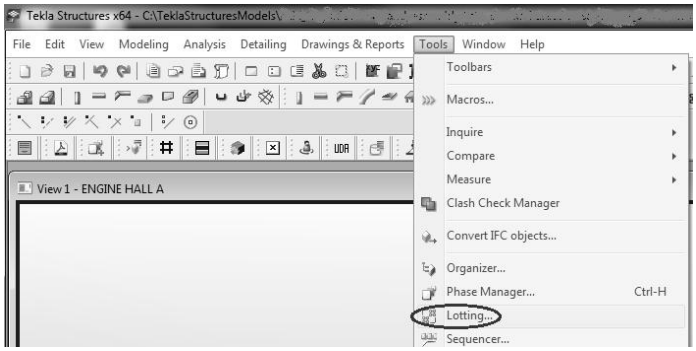
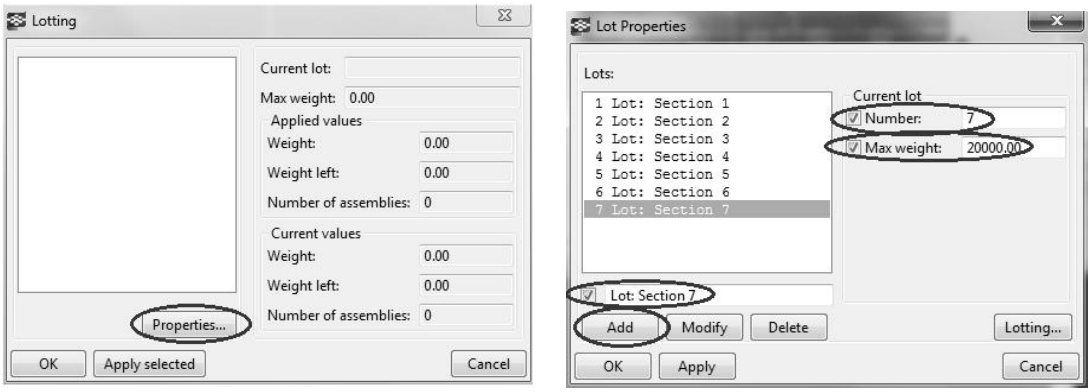


Figure 9.55 *The location of the Lotting tool in the model toolbar.*



Figures 9.56 and 9.57 *Navigating to the Lot Properties window and creating a lot.*

Objects can be chosen in the Organizer tool for attaching them a lot number and a lot name. You can only choose part groups, not assembly groups in the Organizer.

In the following example we will inspect weight of each section of Engine hall A. We have created a new category called “Parts by section” and a subcategory “Engine hall A”, attached parts to this category and created a category tree using the “union” function. Union is set between the section subcategories of “Building” main category and “Engine hall A” subcategory in “Parts by section” category. These steps have been introduced in a previous chapter. By right clicking one of the section subcategory, selecting “Select in the model” and clicking “Apply selected” icon in the Lotting window we will attach Lot number and Lot name as attributes for selected parts.

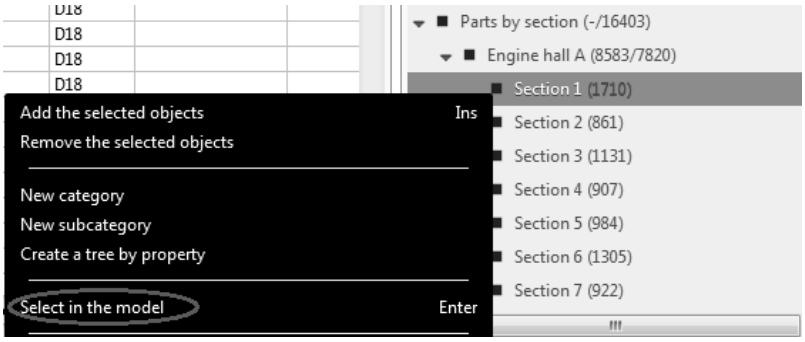


Figure 9.58 *Selecting the parts belonging to Section 1 in part based subcategory tree of Engine hall A.*

Figure 9.59 *Applying objects selected in the model view to the lot.*

Although Lotting window is expressing the number of assemblies included in a lot, lot number is attached to the related parts. This information can also be exported as IFC to Tekla BIMsight. Use the export setting presented in the Figures 9.60 and 9.61. Notice that "albl_name" and "albl_Property_Set" must be named without any space between the characters.

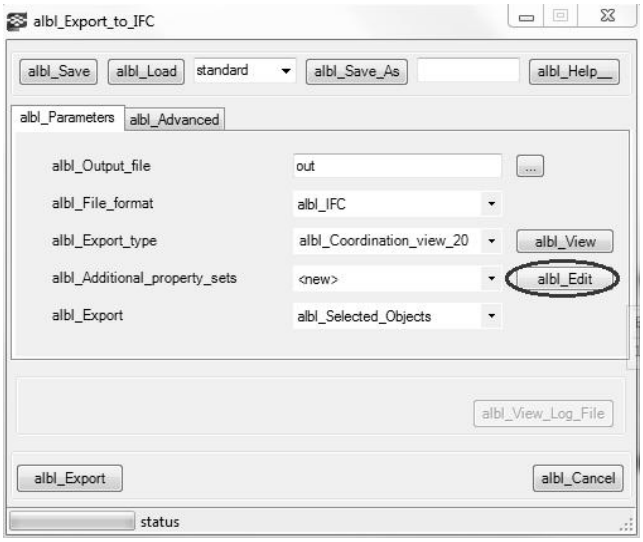


Figure 9.60 *albl_Export_to_IFC window for choosing the export settings.*

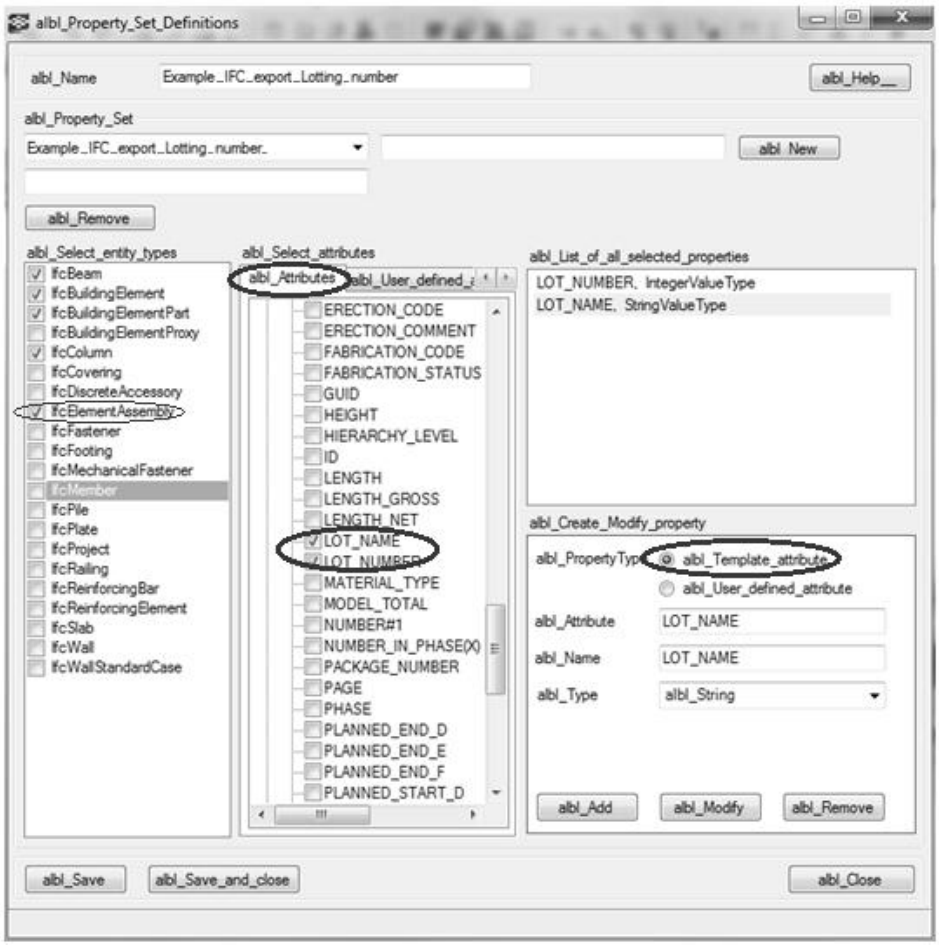


Figure 9.61 *albl_Additional_property_sets settings for LOT_NUMBER IFC export.*

9.1.6.3 Lotting related UDA number set for the model objects

Lotting related number or other mark can be attached to the model parts or assemblies by attaching number to delivery related UDA field. There are three this type of fields in part and assembly properties by default: UDA_Delivery_number, UDA,Package_number and UDA_Shipment_number in the "UDA_Fabrication" tab. UDA_Package_number is the most suitable of these three for identifying containers in the preliminary frame element packing design. You can easily attach this number for parts or assemblies once you have created categories and attached the parts or assemblies in the categories using the Organizer tool. Creating the categories in the Organizer tool and attaching UDA information for parts or assemblies in the way that has been presented in the previous chapters. Notice that it is not practical to use lotting related UDA number identically to the installation sequence numbers.

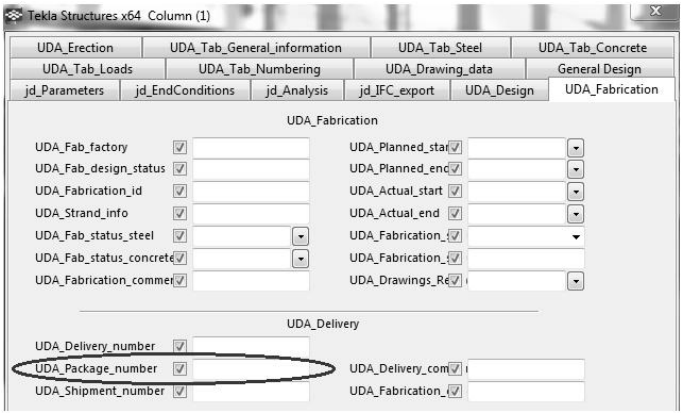


Figure 9.62 *UDA_Package_number field in user-defined attributes property window for a part.*

Lotting related UDA number can also be exported as IFC to Tekla BIMsight. Use the export setting presented in the Figure 9.63. Notice that "albl_name" and "albl_Property_Set" must be named without any space between the characters.

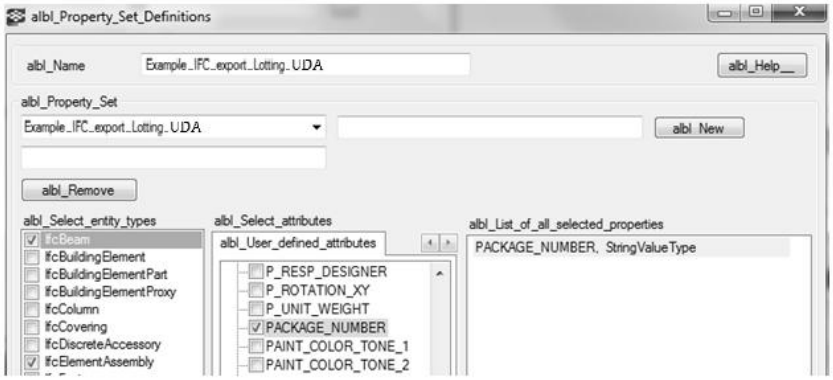


Figure 9.63 *albl_Additional_property_sets settings for IFC export of UDA PACKAGE_NUMBER.*

9.1.6.4 Lotting information provided by the supplier

The frame element supplier is providing excel form packing lists equipped with the tree digit container number. This number can be inserted to model parts and assemblies as UDA data. Proper attributes for describing a container number would be aforementioned lot number or package number presented as object attribute. At the moment the container number must be set manually for each object, so it is not yet practical to model packing list information. In order to promote BIM based packing list management Tekla Structures should have tools, integrated for example to the Organizer tool, for importing excel sheets first created in the tool and then completed with assembly specific package numbers by the supplier. This information could then be exported to Tekla BIMsight and used for management of container unloading.

9.1.7 Organizer: Creating assembly list template

Assembly list template is similar to "Assembly list – UDA Erection code" template we created in chapter 9.1.4. The only difference is that it is based on Assembly number based grouping, not installation sequence number based grouping. Installation sequence

number column is located at the right side of the template for indicating the frame element supplier the right packing order.

Figure 9.64 *Assembly list template settings.*

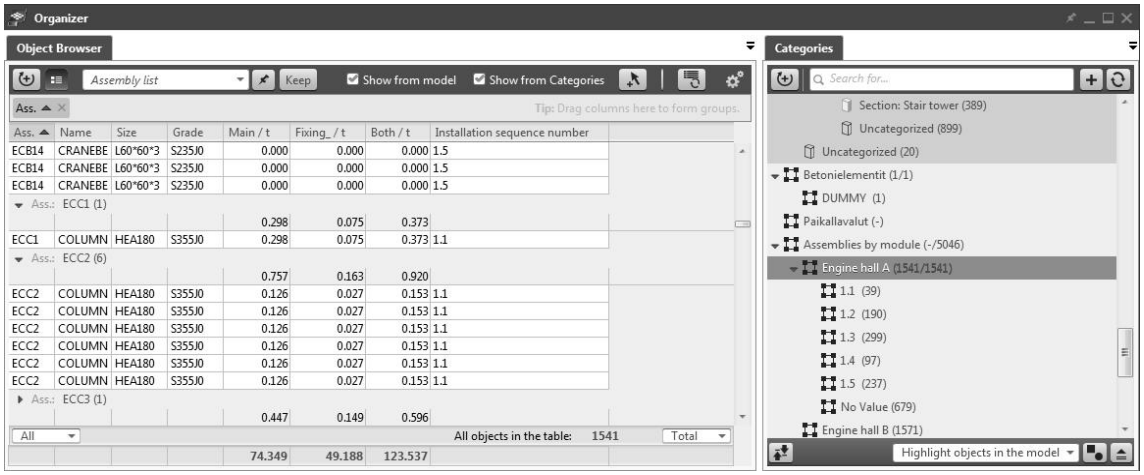


Figure 9.65 *Appearance of the assembly list template in the Object Browser.*

9.1.8 Organizer: Grouping assemblies to assembly list category

Next we will create a category for module based assembly lists. The categorization will only include assemblies delivered by the frame element supplier excluding all the other assemblies located in the volumetric area of the module. This categorization is not needed if frame element assemblies are already filtered to "Assemblies by module" category using View Filter.

First create a new category called "Assembly lists" and a subcategory for all the separate assembly lists. In our example case assembly lists are based on the modular division and the categories are called Engine hall A, Engine hall B, Utility block and Stair tower. Right click subcategory "Engine hall A" and choose "Properties". Set the subcategory to only include assemblies and choose the property template to be "Assembly list".

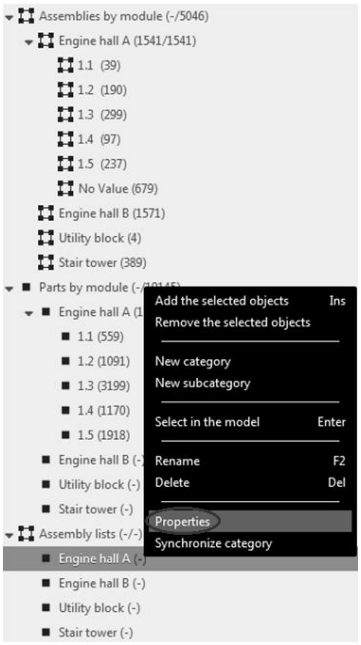


Figure 9.66 *Setting properties for assembly list subcategory.*

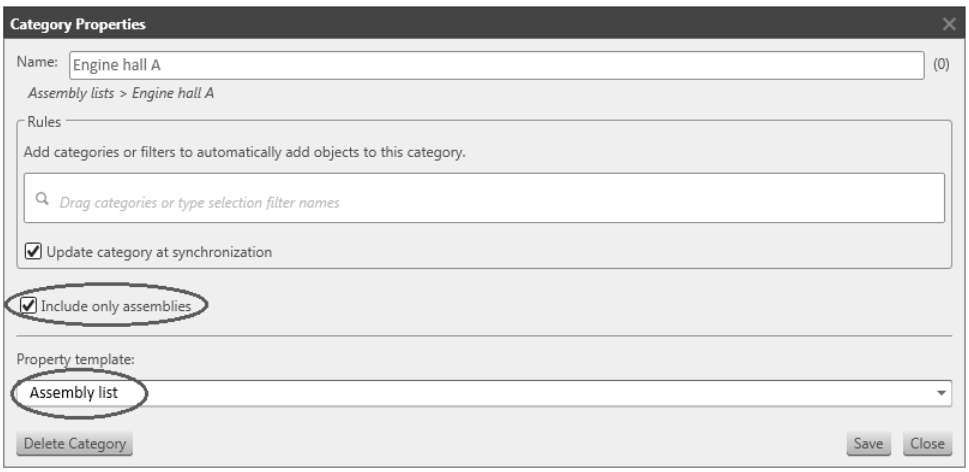


Figure 9.67 *Setting properties for assembly list subcategory.*

In “Assemblies by module” category and “Engine hall A” subcategory, choose “Assembly list” template. Now you have activated a template representing assemblies alphabetically. Choose all the assemblies to be included in the assembly list using Ctrl and Shift buttons. Right click one of the selected rows and choose “Select in the model”. Right click “Engine hall A” subcategory in “Assembly lists” category and choose “Add the selected objects”. Since gridline based boundary boxes are used for grouping the objects in “Assemblies by module” category some of the objects may be located in a wrong subcategory. In our case for example, some objects belonging to Engine hall A were located in Stair tower subcategory. Therefore it was necessary to add these objects manually in “Assembly lists > Engine hall A” subcategory.

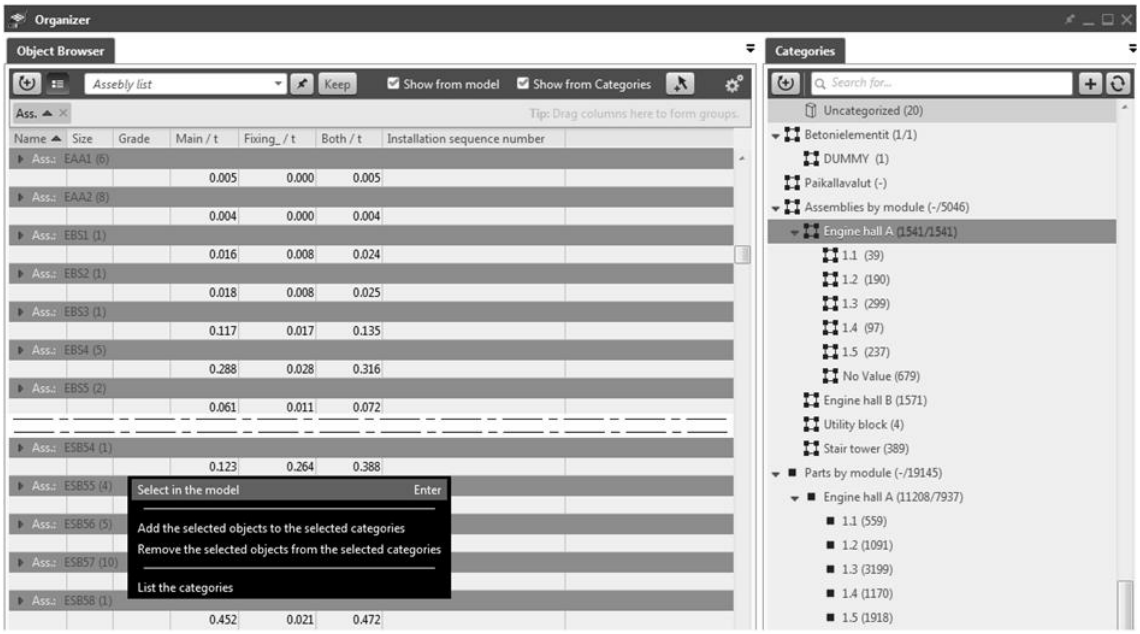


Figure 9.68 *Selecting objects in “Assemblies by module > Engine hall A” subcategory to be attached to “Assembly lists > Engine hall A” subcategory.*

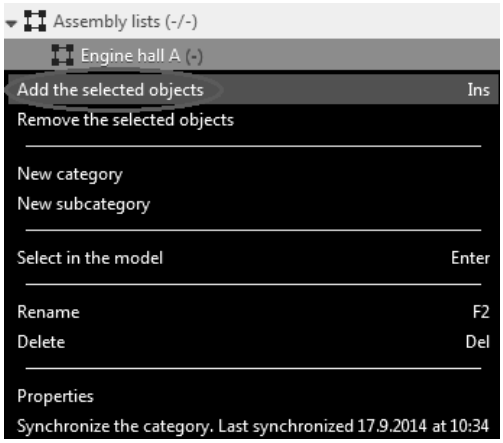
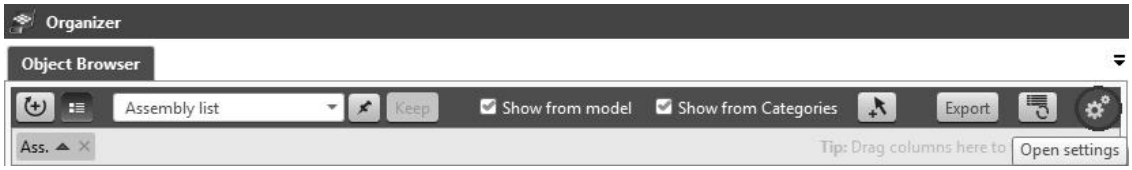
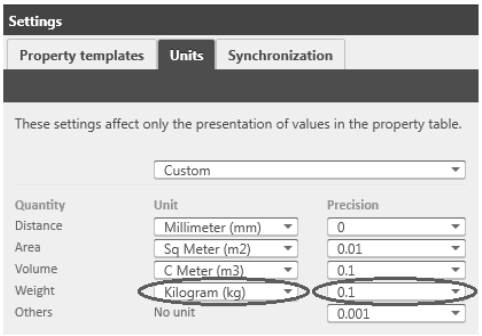


Figure 9.69 *Adding selected objects to “Assembly lists > Engine hall A” subcategory.*

9.1.9 Organizer: Exporting assembly list as excel file

Assembly list is expressing weight of assemblies as kilos. In our Organizer settings weight is expressed as tons (t). To change the setting click “Open settings” icon in Object Browser, and go to “Units” tab. Change Unit column as “Kilogram (kg) and Precision column as “0.1” in Weight row.





Figures 9.70, 9.71 and 9.72 *Steps to change weight unit and precision in the Organizer.*

Assembly list can be exported to excel by clicking “Export” icon in the Object Browser. Choose the desired template layout in the computer hard drive or company specific database. By choosing the default template the template will receive an excel appearance made my Tekla Corporation.

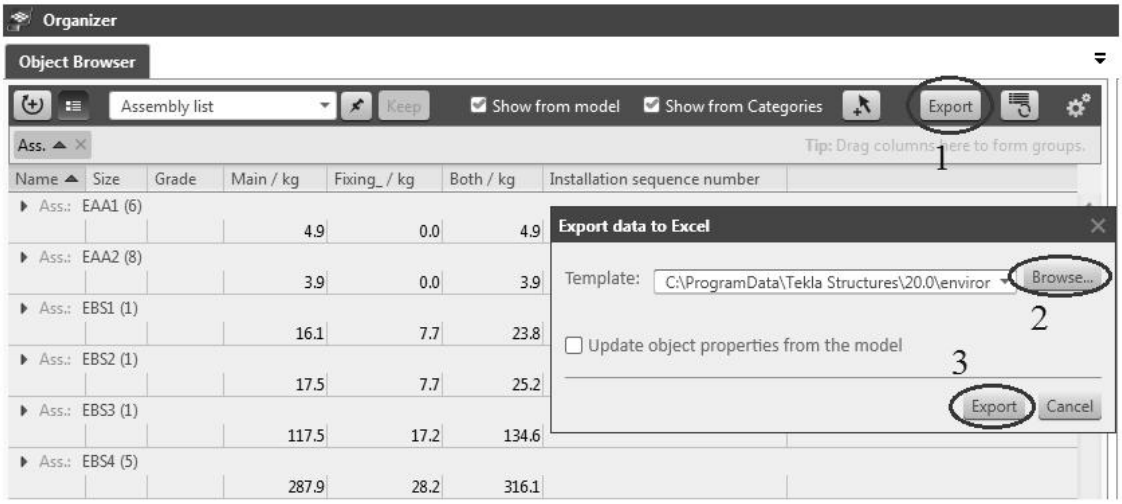


Figure 9.73 *Steps to export an assembly list as an excel file.*

9.2 Tekla BIMsight

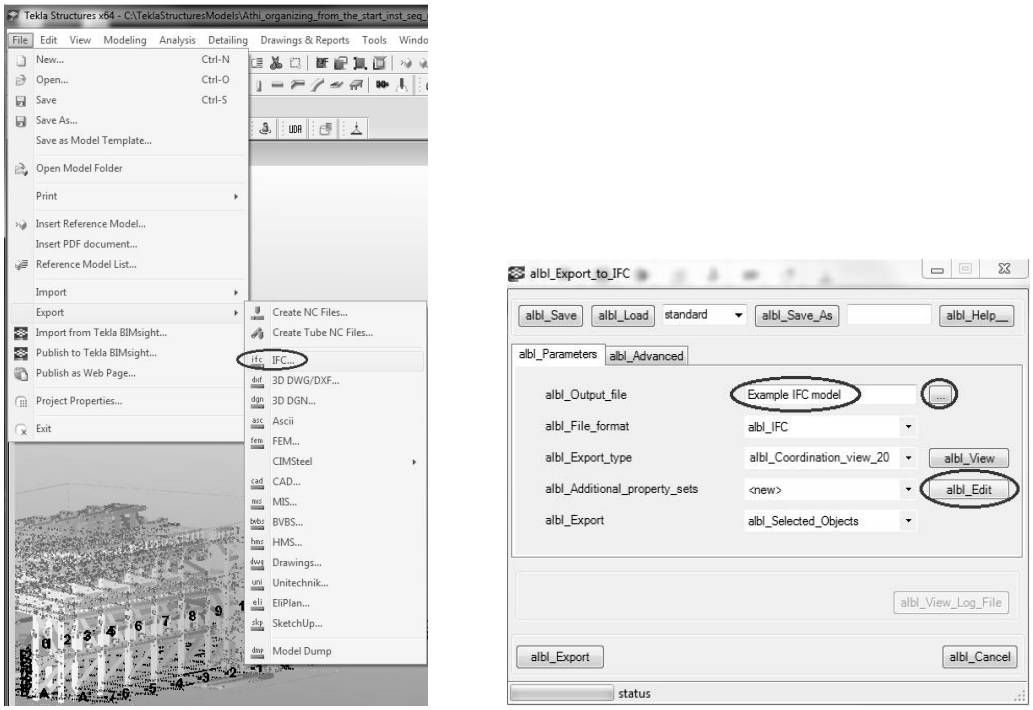
In this chapter we will explain how to export IFC model with installation sequence number and inspect it in Tekla BIMsight using a project folder. We will also introduce ways to inspect object grouping and other object data in Tekla BIMsight. These properties will pay regard to needs of site team what it comes to management of frame element unloading and installation works.

9.2.1 Exporting Tekla Structures model with installation sequence data to Tekla BIMsight

IFC model with selected attributes created from Tekla Structures model can be uploaded to Tekla BIMsight project folder. Other option is to directly publish Tekla BIMsight model in Tekla Structures. This option can only be used in the design phase since attributes that can be exported to BIMsight are limited. Instead, if IFC model is first exported to the project folder and attached to Tekla BIMsight project, range of exported object attributes can be chosen by oneself.

Publishing Tekla BIMsight model directly in Tekla Structures has been introduced in chapter 7.4.1. Next we will introduce how to export IFC model, create a project folder and bring the IFC model to Tekla BIMsight project view. Steps for these actions are the following:

1. Select the objects that you want to export to Tekla BIMsight project. Click “File > Export > IFC…”. Choose the project folder location and name for the export in “albl_Output_file” field. Change “albl_Additional_property_sets” by clicking “albl_Edit” icon.



Figures 9.74 and 9.75 *Steps to export the model as IFC file, name the export file, choose the file location and set additional property settings for the export file.*

2. Write the name of albl_Name and albl_Property_Set. Make sure that there is no space between the characters. Choose “albl_Select_entity_types” you want to export and activate “ERECTION_CODE” in “albl_User_defined_attributes" tab. Choose albl_PropertyType to be “albl_User_defined_attributes” and click then “albl_Save_and_close” icon.

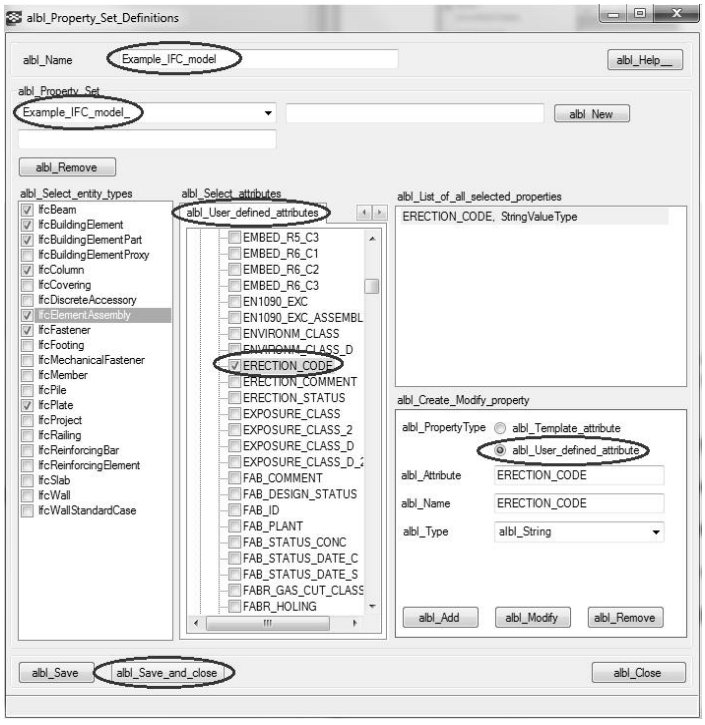


Figure 9.76 *Additional property settings for the export.*

3. Choose the objects to be exported in “albl_Export” field. You can either choose all the objects or selected objects to be exported. In our case we will choose “albl_Selected_Objects”. Click “albl_Export” icon to execute the export.

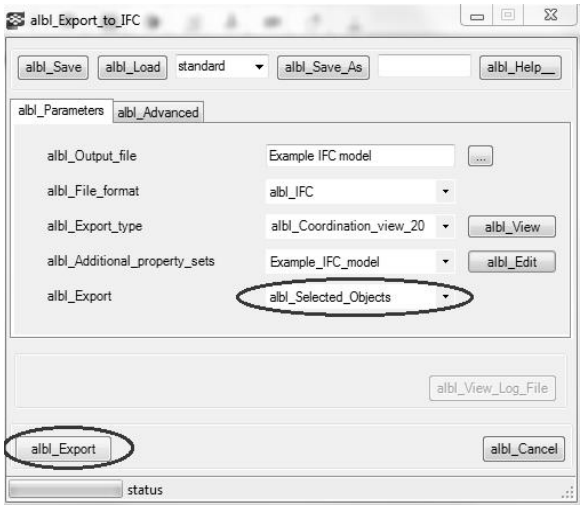
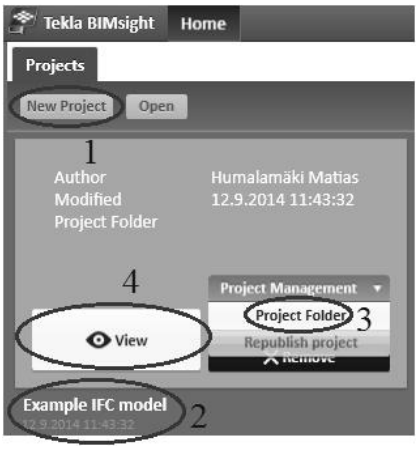
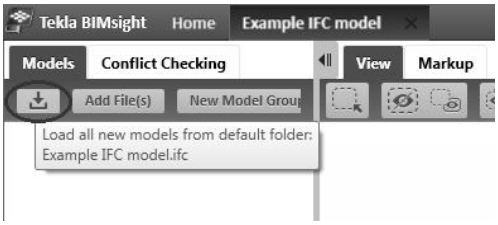


Figure 9.77 *Steps to select objects to be considered in the export and executing the export.*

4. After the IFC export file has been created, open Tekla BIMsight and click “New project” icon in Home tab. Name the project as you desire. In our case we have name the project as “Example IFC model”. Move the export file to the project folder if it hasn’t already been exported there. Click “Project management > Project Folder” to set the project folder. You can choose project folder to be any folder visible in your computer including a cloud or a network folder. Click “View” to open the Tekla BIMsight session. Then click “Load all new models from default folder” icon to access the IFC model.





Figures 9.78 and 9.79 *Steps to set the project folder and load the IFC export to the Tekla BIMsight session.*

5. You can attach all the separate models located in the project folder under one file by clicking “Save as a Package” in the Home tab. Choose then the file name

and location for the Tekla BIMsight model package. Tekla BIMsight model is now ready to be sent for other project stakeholders.

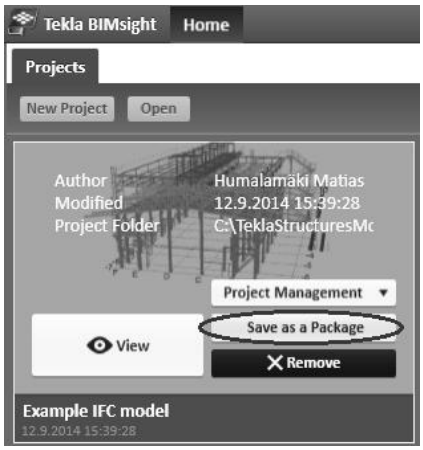


Figure 9.80 *Attaching all the separate models under one Tekla BIMsight model by saving the project as a package.*

9.2.2 Managing BIM data at the site

9.2.2.1 BIM based assembly plan and progress report

One of the most useful ways to use Tekla BIMsight in installation management is to arrange objects by "Selected state" and then sort them by "Assembly mark". Main parts of the assemblies are selected by pressing Ctrl button and selecting the main parts in the model view. Selected objects with their assembly marks are presented in the Objects tab. Main parts are chosen since it is not currently possible to choose whole assemblies in the model view.

Site supervisor can save the view with selected objects as a slide show slide. He can, for example, mark all the objects to be installed next day and present the view with related assembly numbers in the Objects tab for the construction workers. Construction workers can then gather the elements presented in the model view in the installation area. Slides and aforementioned object grouping and sorting settings can also be used for making a BIM based assembly plan for the whole building.

In this case every slide is named after the date the installation is planned to take place. Setting the model color grey and partly transparent, creating and naming slides, and saving a slide show has been introduced in Chapter 8.

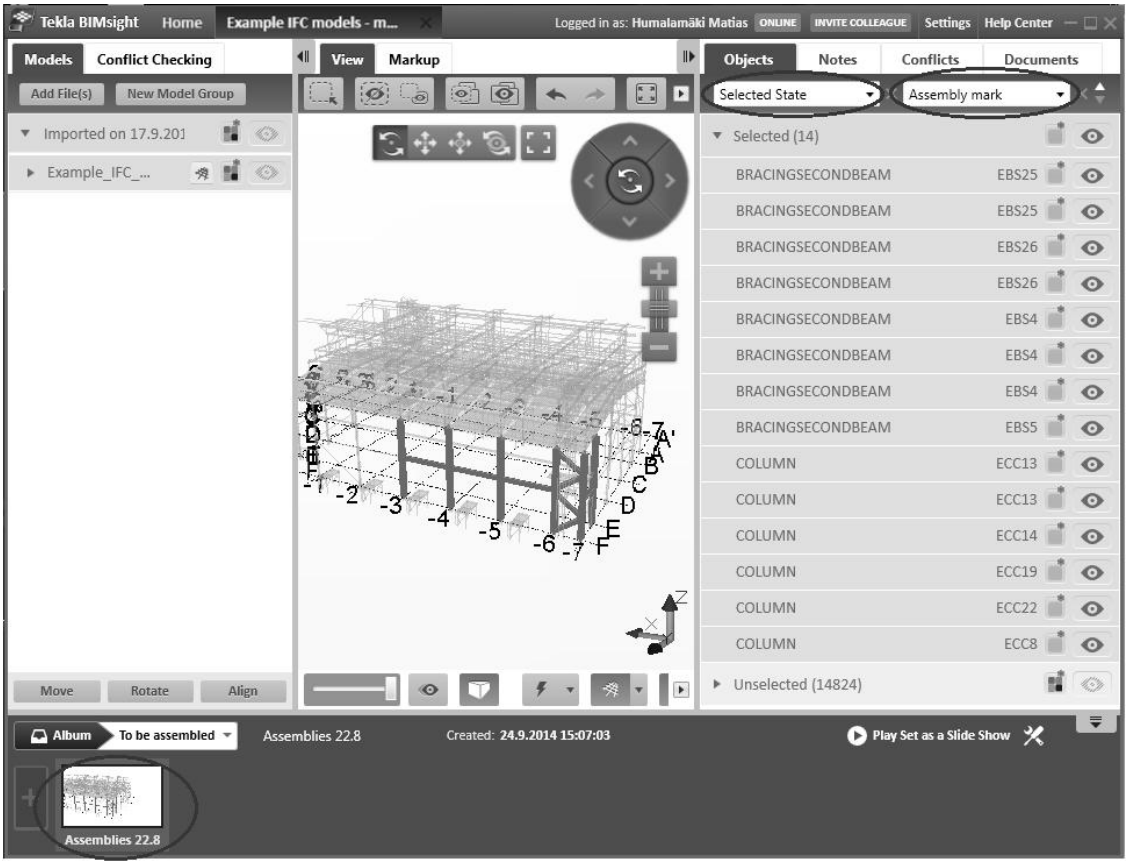


Figure 9.81 *Object grouping and sorting settings for inspecting assembly mark of selected objects and saving the assembly plan view as a slide.*

Slide show slides and same object grouping and sorting settings can be used for monitoring and reporting progress of the installation works. BIM based monitoring of progress is used so that the Site Supervisor can follow the progress and plan upcoming installation works. In our example slides are named as “Installed by xx.xx”, xx.xx being a date. New progress slide can be created in the previous progress slide by pressing Ctrl button and choosing the new objects to be presented in new progress slide. You must then click “+” icon to create a progress slide and name it according to the related date.

Figure 9.82 *Creating an installation progress related slide based on the previous installation progress slide.*

Assembly plan and installation progress related slides are stored to their own albums. In our case we have named assembly plan related album as “To be assembled” and installation progress related album as “Progress” Albums can be created by having two slide icons and dragging one of these icons on top of the other slide icon.

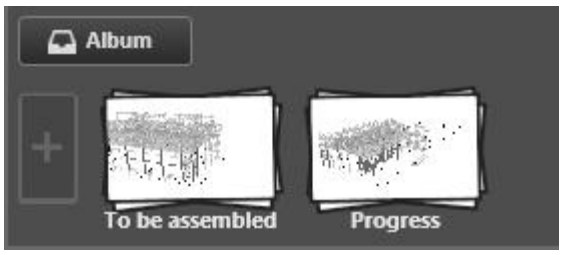


Figure 9.83 *Albums for assembly plan and installation progress slides.*

Information presented in slide show slides can be brought to a note so that it can be delivered to other project stakeholders. You can attach multiple views in one note if you save the note in shared folder. If you send the note as an e-mail or other separate file you can only attach one view to one note.

In the following example we will create and share a progress report as a note. Same method can also be used for sharing an assembly plan as a note. Add a new note in Notes tab and set it to be public. Create a note view by double clicking the desired slide view and clicking “Add Current View” icon. Repeat these actions for all the slide views which you want to attach to the note. You can also link objects related to the views to

the note by clicking “Link to Selected” icon. Write a description containing desired view text data for the note. Click “Save” icon to save and share the note.

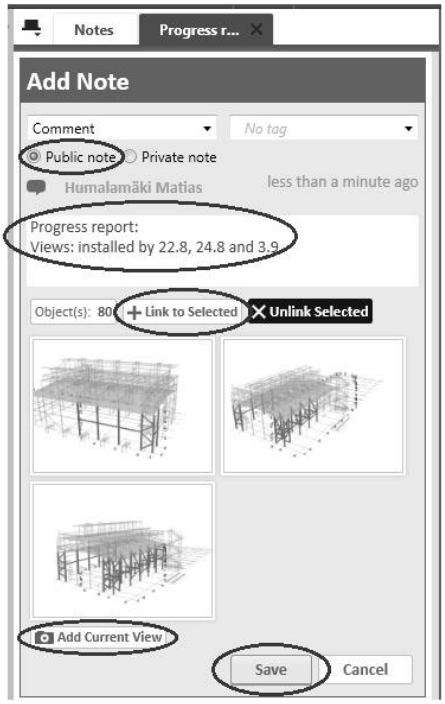
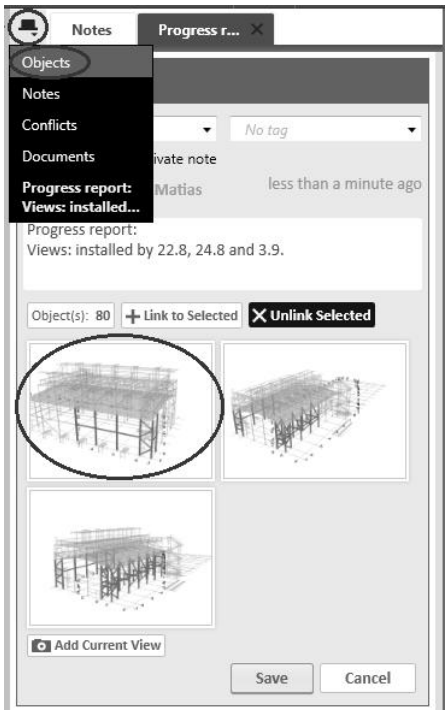
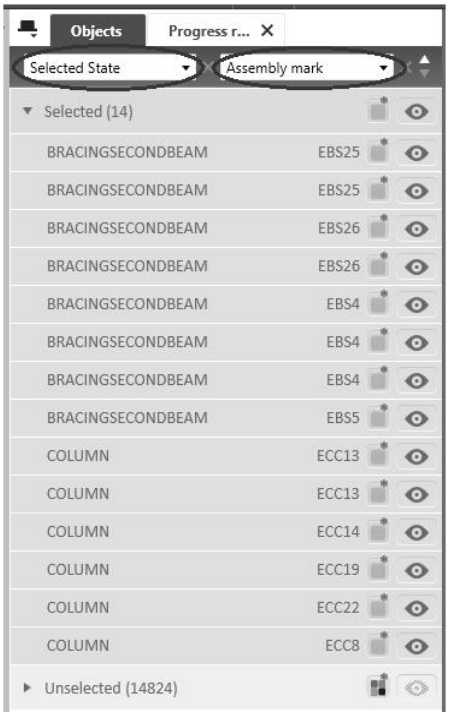


Figure 9.84 *Steps to create slide view based note and publish the note.*

All the linked objects can be quickly reviewed by clicking “Object(s)” icon in the note. Furthermore, the receiver of the note can inspect data of one view by clicking the view, Selecting the Objects tab and grouping the objects by “Selected state”. In our example objects are then sorted by “Assembly mark”.





Figures 9.85 and 9.86 *Steps to inspect progress report note data by a note receiver.*

You can examine assembly weights in an installation progress slide by grouping objects by “Selected State” and sorting them by “AssemblyWeight”. Notice that the order of objects in the list sorted by “AssemblyWeight” is not the same as when sorting them by “Assembly mark”. Notice also that we have only selected main parts and sorting objects instead by “Weight” will only illustrate weight of the selected main parts. This information can’t be used for a progress report.

Progress of installation works is usually expressed as kilos. If you have weight data expressed as tons by default you can change tons to kilos in “Settings” window that can be opened in the upper right corner of Tekla BIMsight view. You can also change weight precision in the same window.

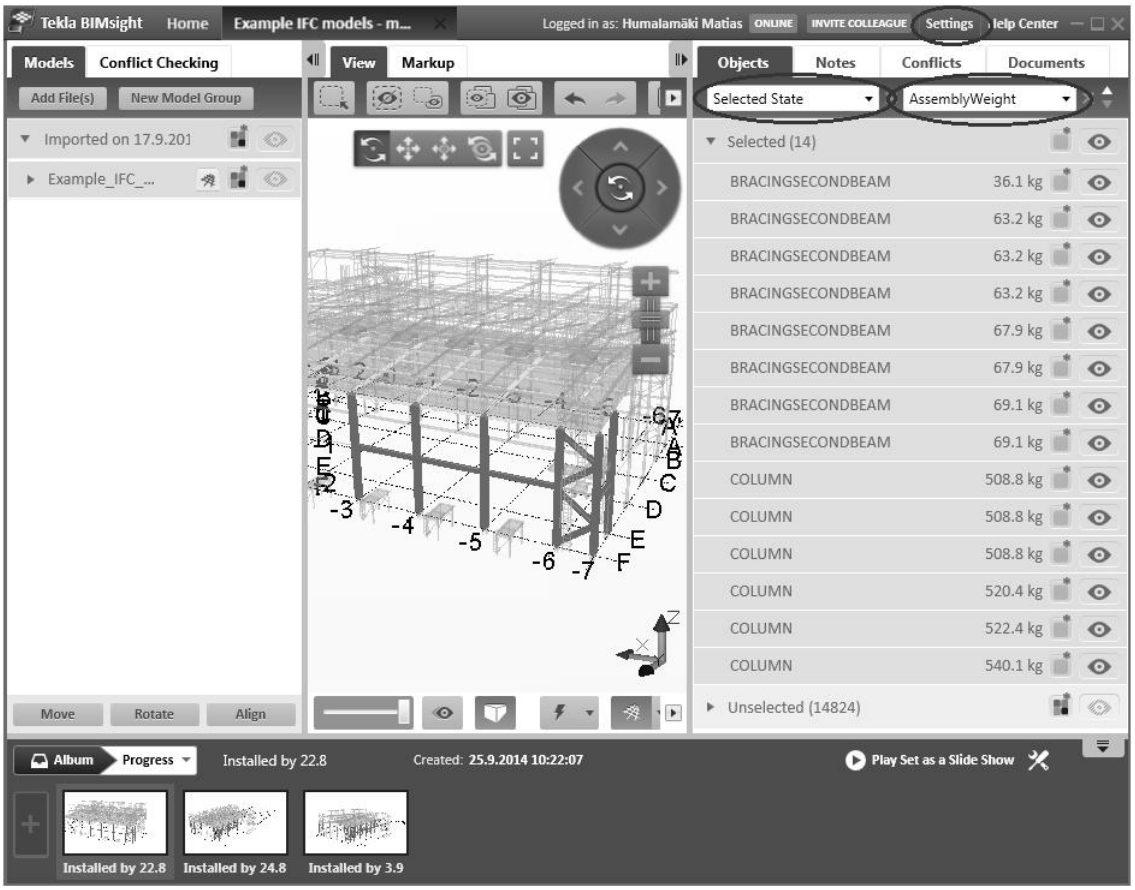


Figure 9.87 *Object grouping and sorting settings for inspecting assembly weight of the objects related to the installation progress slide, and changing settings of weight unit and precision.*

It would be useful for making progress report if total weight of the selected assemblies could be inspected in Tekla BIMsight. At the moment this is not possible and total weight of selected assemblies must be calculated manually or in Excel. According to Tekla Corporation, adding aforementioned property for the software is considered and it might be implemented in the future [14].

9.2.2.2 Inspecting bolt data

Bolt types can be examined by grouping objects by ”Bolt size” and sorting them by ”Bolt length”. Bolt lengths and diameters are presented in Objects tab and the selected bolts are highlighted in the model view. Notice that one “MechanicalFastener” raw is expressing a group of bolts needed between two assembly parts. As a result, the number next to a bolt diameter group is expressing quantity of bolt groups within one bolt size.

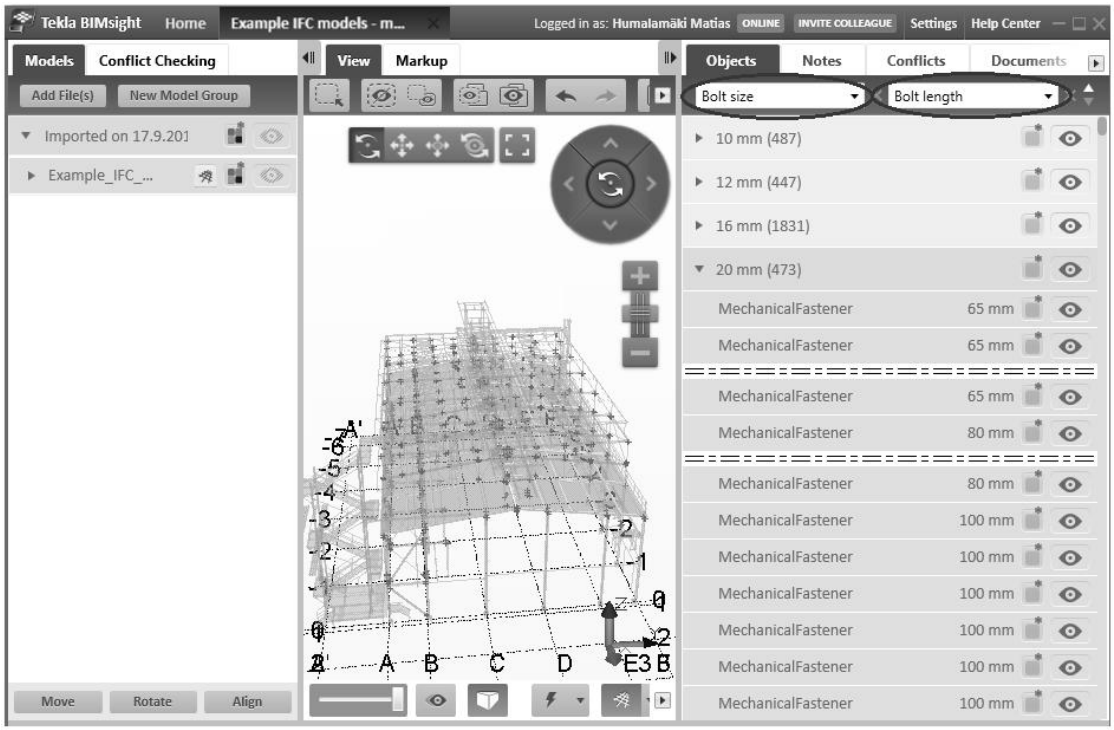


Figure 9.88 *Bolt grouping and sorting settings for inspecting bolt type specific bolt locations.*

You can also examine bolt data one at the time by double clicking bolt group in the model view and then double clicking related object highlighted in the Objects tab. Appearing tab will show all the bolt data exported to IFC such as bolt diameter, length, material type and bolt hole diameter. It will also express connected assemblies if this attribute is chosen to be exported in Tekla Structures.

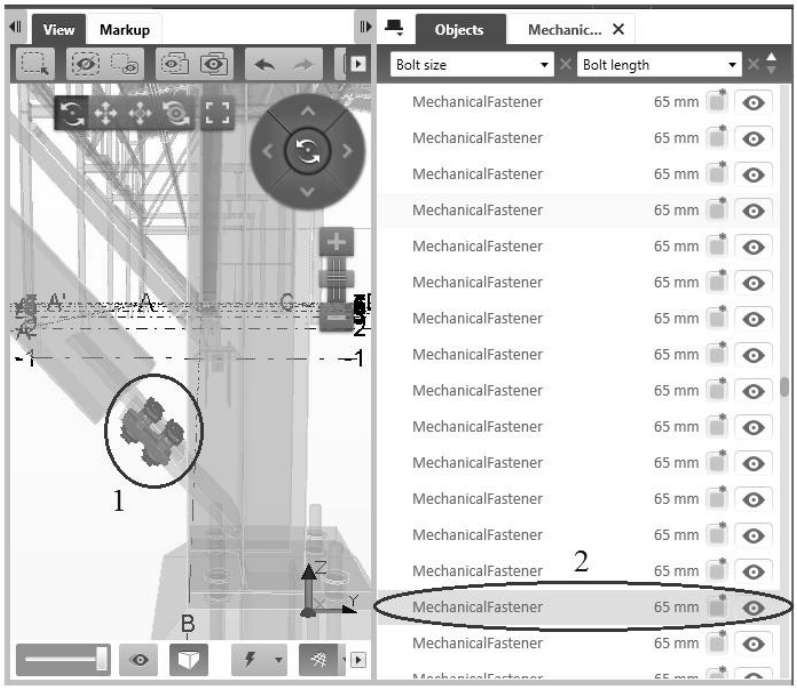


Figure 9.89 *Steps to examine properties of one bolt group.*

Figure 9.90 *Bolt properties of the selected bolt group.*

9.2.2.3 Installation sequence numbers

Installation sequence number data can be utilized and arranged in many ways in Tekla BIMsight. The best way to select grouping and sorting options in Object Browser depend on the need of current situation at the construction site. One good way is to group objects according to the ERECTION_CODE and sort them by Assembly mark. Since the frame element supplier has packed the elements based on the installation sequence

numbers, you can use these object groping and sorting settings for making slide view assembly plans.

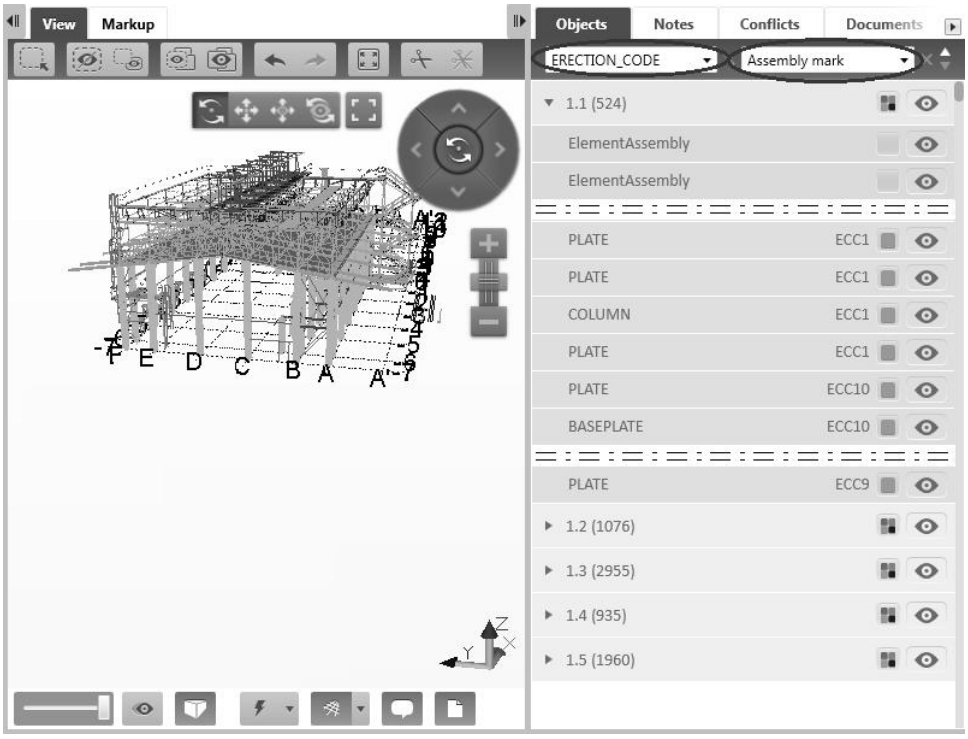
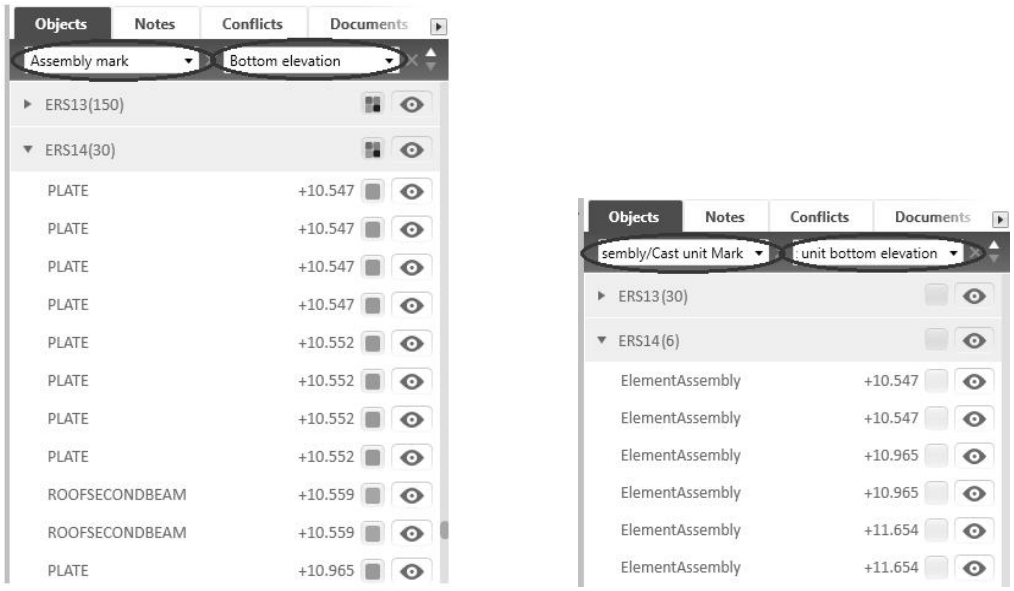


Figure 9.91 *Steps to select objects to be considered on the export and executing the export.*

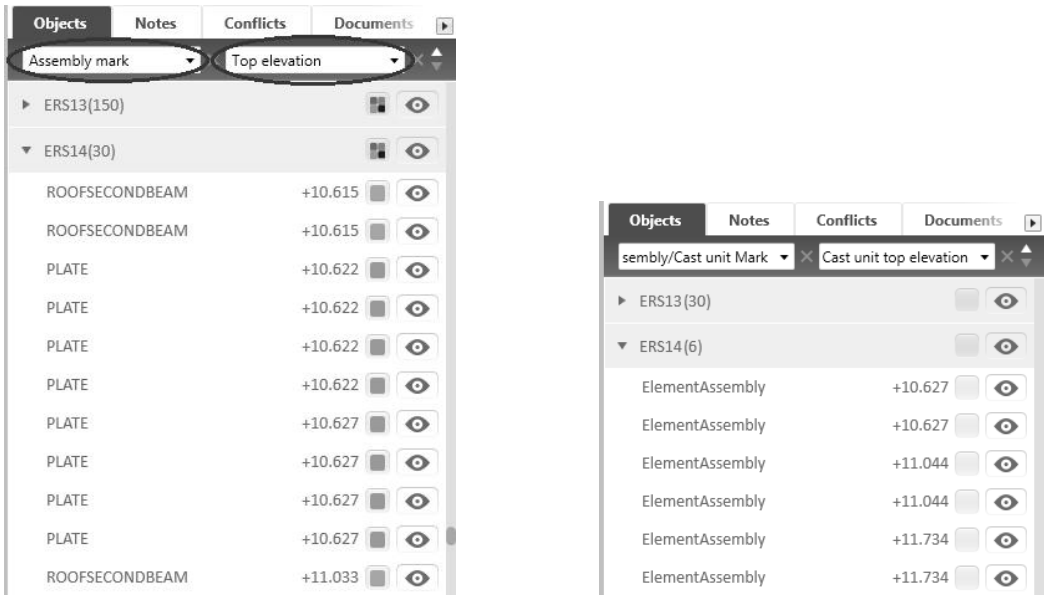
9.2.2.4 Elevation of assemblies and parts

One way to ease frame installation management at the site is to utilize assembly mark specific elevations found in the model. If you first group object by "Assembly/Cast unit Mark" and sort objects by "Assembly/Cast unit bottom elevation" you can verify assembly number specific elevations during the installation works. Deficiency in this grouping is that you can't see the location of the element assembly in the model view. On the other hand, you can first group objects by "Assembly mark" and sort them by "Bottom elevation" to both inspect part location in the model view and see the bottom elevation of the part.



Figures 9.92 and 9.93 *Grouping and sorting setting for inspecting bottom elevation of parts and assemblies.*

You can also examine top elevations of both parts and assemblies. In case of parts sort the objects by "Top elevation" and in case of assemblies "Assembly/Cast unit top elevation".

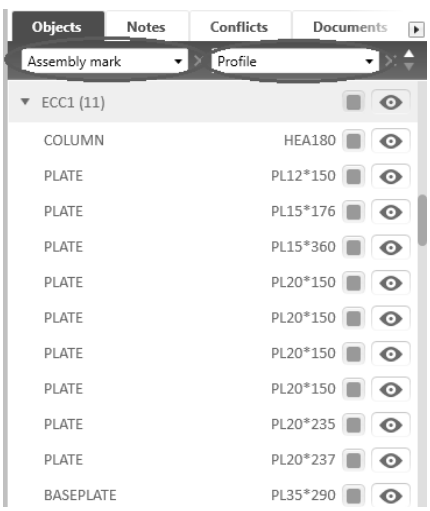


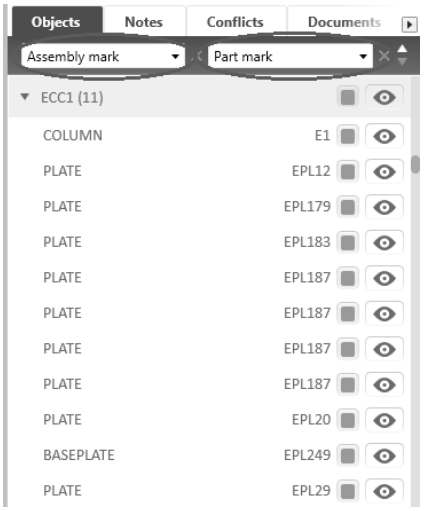
Figures 9.94 and 9.95 *Grouping and sorting setting for inspecting top elevation of parts and assemblies.*

9.2.2.5 Management of design or manufacturing mistake

Sometimes there can be a flaw in the shape of an element caused by a manufacturing mistake. In this case you may need to track the profile or part mark to fix the element. Assembly specific part profiles can be tracked by grouping the objects by "Assembly mark" and sorting them by "Profile". Part mark can be inspected by grouping the objects by "Assembly mark" and sorting them by "Part mark". Using aforementioned grouping and sorting settings along with the model assembly view you can, for exam-

ple, find similar part to be welded in right location of the element. You can also order the missing part or check if there is such part in site extra parts using the Part mark. These grouping and sorting settings can't be used if holes for the bolts are located in the wrong place.





Figures 9.96 and 9.97 *Grouping and sorting setting for inspecting assembly specific profiles and part marks.*

9.2.3 Objective: BIM based installation management without assembly drawings

A long-term goal would be to replace assembly drawings with BIM application suitable for on-site work. At the moment Tekla BIMsight doesn't contain functions to inspect objects attributes in the model view. Instead, attributes are presented in Objects tab according to object grouping and sorting settings. Therefore you can't inspect assembly numbers and bolt types in the model at one glance. Dimension lines must be added manually in Tekla BIMsight model view. In traditional 2D assembly drawings all this data needed for installation management is visible in one view.

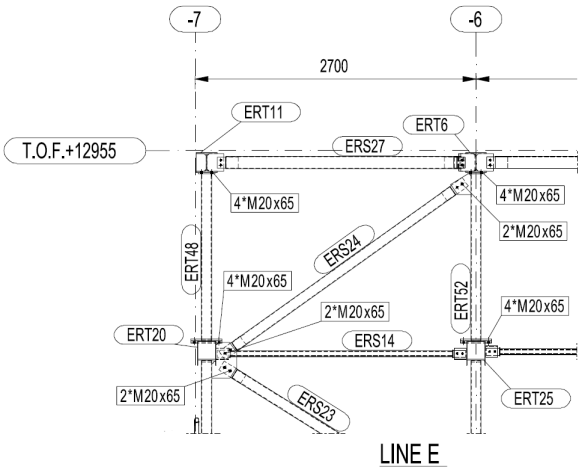
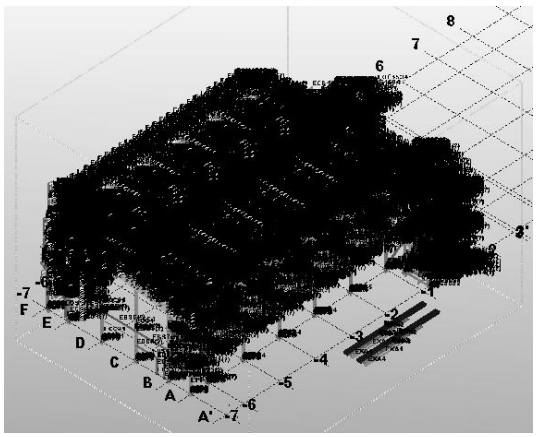
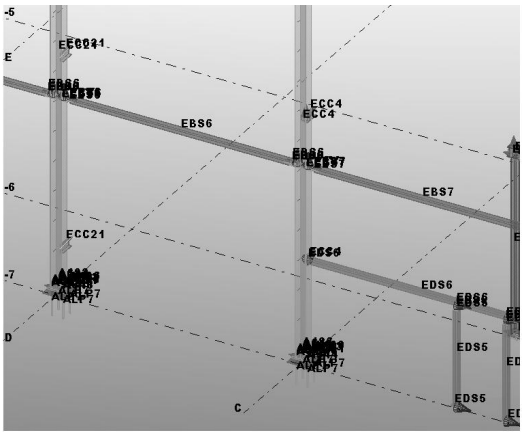


Figure 9.98 *Example view an assembly drawing containing information of assembly numbers, bolt names and quantities, measurement lines, gridlines and elevations.*

Assembly numbers can be examined in the model view in Tekla Structures by clicking "View > View properties…", clicking "Display…" icon, navigating to "Advanced" tab, activating Assembly position as Part label and clicking "Modify" icon. Now you have all the assembly numbers visible in the model view at the same time. The problem is that besides model being now messy, you can't export these numbers to be visible in Tekla BIMsight. [15] Also measurement lines and other data found in assembly drawings are not possible to export as model view.





Figures 9.99 and 9.100 *Assembly numbers visible in Tekla Structures model view.*

It would be optimal if these attributes would be attached to Tekla BIMsight model view along with related dimension lines. On the other hand, if all the assembly numbers, measurement lines and bolt names would be simultaneously visible in the model view the result would be really messy. In order to get all the essential assembly data visible in model view in a reasonable way all the attributes should not be visible at the same time. One option would be that only the assembly numbers of main assemblies would be visible in the whole model view. When zoomed in detail view also dimension lines, bolt names and secondary assembly numbers would be visible.

Other option is that assembly numbers, bolt types and dimension lines would set to be separate objects in Tekla Structures and exported as a separate IFC model or models in addition to the actual structural IFC model. One of these extra IFC models would only include aforementioned data for a small section of the model so that messy appearance would be avoided. These separate IFC models could then be moved to the project folder and be hidden in Tekla BIMsight view when not needed.

10 PROPOSAL FOR CONSTRUCTOR'S BIM BASED INSTALLATION LOGISTICS AND PROJECT MANAGEMENT SYSTEM

This chapter presents main points of BIM protocols that are recommended to be implemented in Wärtsilä's protocols. It is considering the needs of the stakeholder companies introduced in chapters 5 and 6. On the other hand, this chapter specifies software properties presented in chapters 7, 8 and 9 based on the interviews. As a result, we will define a sketch of BIM based installation logistics and project management system for the constructor.

BIM based communication has proven to be an effective tool for enhanced collaboration throughout the project. There is also potential to expand application of this technology in other fields than mere communication. For example, same communication tools can be used for supervision of site works and, in big picture, for storing customized BIM data.

Standardizing modular size of the engine hall and dividing engine hall assemblies for installation sequence number groups is a practical way to manage frame installation sequence based packing order. It is also easy to implement by Structural Designers taking care of modeling and by the main frame element supplier as manufacturing and packing point of view. Systemized installation sequence grouping based on element types and group weight can be utilized for making packing order related assembly plans. It also enables setting more detailed packing requirements compared to the standard division if needed in a project.

10.1 BIM based collaboration and communication

BIM based collaboration and communication between Structural Designers, Project Engineers and Site Supervisors can be implemented through three different ways. One option is to establish an interactive internet cloud type of project folder, such as Dropbox, in which all BIM related collaboration data is stored. Other option is to share this data by e-mail. Third option is to store the information in the constructor's project bank.

Dropbox type of BIM collaboration and communication protocol is the best option of these three systems and all the collaboration related modeling data is stored there. Files located in the shared folder are also interactive, in other words they will be automatically updated for others once one have made his changes. The system is simple as technical and visual point of view and the project stakeholders are saving time since the files are not required to send from one to another.

Communication between the stakeholders is implemented using note stored in the project folder. Notes can be managed by default in Tekla BIMsight but in Tekla Structures there must be an extension tool called Comment tool installed in order to receive and send comments. Since notes can be either private or public, they can be used for both communication and storing stakeholder specific data before sharing it with others.

Every shared note is part of a question-answer tread containing a field for a note status. When the issue presented in the beginning of this chain is solved, the status will be updated to "solved" or "closed". Same notes files are compatible for the communication between all stakeholders. This means that besides note file based communication between Structural Designers and Project Engineers or Project Engineers and the site team, notes published by the site team can automatically be inspected and answered by structural design team.

When the project is starting, an interactive cloud folder located in Dropbox or other similar file sharing service is created and set to be the project folder in Tekla BIMsight. Structural Designers will then export IFC model in Tekla Structures to this project folder. MEP Designers will also export their models as dgn file to the same folder.

As the design process proceeds, new revisions of these models are exported in the project folder. Old revision is automatically deleted in the folder if the same name as the old revision is used in the new revision. This procedure is recommendable so that the Tekla BIMsight project won't become too heavy and messy. New revision is pointed out as an update icon in the project model list. If project model must be relocated, made changes in location can be updated for other Tekla BIMsight users by republishing the project.

Structural designer can also enhance revision control and traceability using note files. When publishing a new revision structural designer will also send a note indicating the made changes compared to previous revision. Shared notes are listed according to their publishing date. Therefore a note indicating a new revision can be used as a design milestone in the note list presented in the Commented tool or Tekla BIMsight Notes tab.

Project Engineer and Site Supervisor can create slide views and markups, and attach documents to objects in Tekla BIMsight project view. Saved data is stored to ProjectData.tbp file located in the project folder. This data is for personal use and not visible for other Tekla BIMsight users. Instead, note files can be used for sending views with attached objects and markups between the Project Engineer and the site team. These notes can be based on personal slide views. It is possible to attach several view with link to related objects to one note.

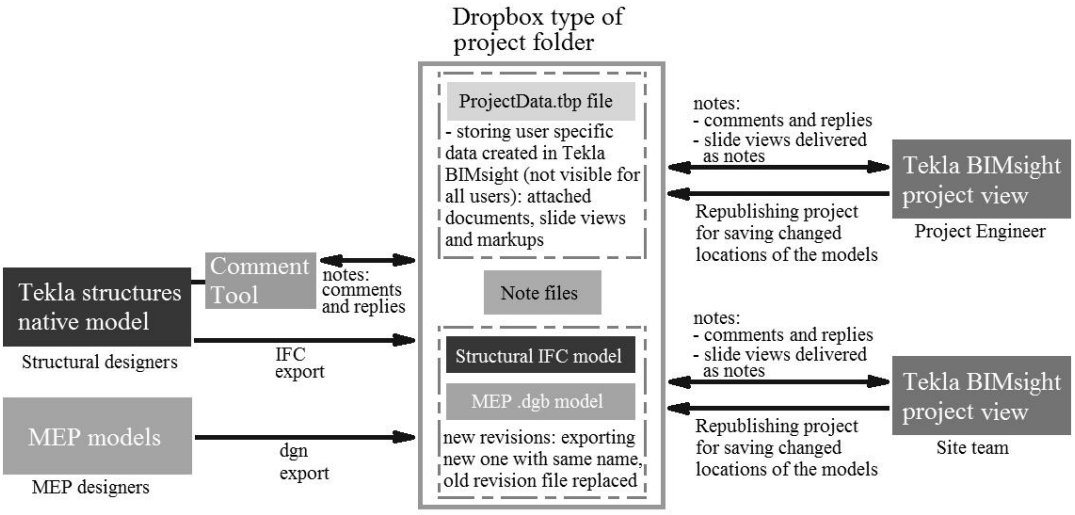


Figure 10.1 *Sketch of BIM based communication and collaboration protocol between designers, project engineers and a site team.*

Full version of Tekla BIMsight is available for PCs and Windows 7 and 8 tablets. If iOS or Android mobile tools are used a separate application, Tekla BIMsight Note, is required to use. This application only allows reading and writing notes.

10.2 Modeling process, model categorization and creating assembly lists

Structural designers are mainly using a Tekla Structures model of an old project as a layout to the designed building. Locations and measurements of the objects are mainly modified during the design process and some objects are added or deleted. Still, majority of the objects are established at the beginning of the project. Assembly and part prefix information is standardized so it is not changed when old model is used in a new project or when new objects are added to the model.

If Tekla Structures version 20 is used in the project categorizing the model is started with setting boundary boxes for location at building, section and floor level. This is implemented using Organizer tool and can be made even if there is no object yet located in the model.

After the boundary boxes have been set assemblies are categorized by module using the Organizer. Installation sequence number can then be attached to assemblies either using the Organizer, View filter or both of the tools. Then assemblies are grouped to assembly list categories in The Organizer based on their modular location. Since the assemblies have been categorized for module based subcategories using the volumetric boundary boxes, some of the assemblies are under the wrong module. For example, some of the assemblies belonging to the Engine hall can be located inside the boundary box of the Stair tower. When assemblies are grouped to assembly list categories these single miss-located assemblies are moved to the right assembly list category. After this assembly lists are ready to be exported as excel files.

Phase division can be used if it is required, for example, due to small storage on the site. The decision is based on the weight of each installation sequence group checked in the Organizer. For instance, trusses are usually necessary to be packed in three or four containers. If the storage area is enabling bringing two containers on the site at one time it is required split the module for more than one phase. Elements belonging to installation sequence group 1.3 (trusses) are then slit to sub installation sequence groups, for instance 1.3.1 and 1.3.2, based on phase division and packed accordingly. Phase division is implemented by splitting a module for more than one phase according to section division and is made using the Organizer and the Phase manager tool.

In order to get installation sequence numbers visible in Tekla BIMsight, they must also be attached to model parts. Parts are categorized by module using the Organizer tool and selecting them in the model view. You can effortlessly attach installation sequence numbers to parts using union-function between "Assemblies by module" and "Parts by module" categories.

Many of the aforementioned steps are not required to be implemented every time a new project is started. Boundary boxes can be set for an empty model layout since gridline stretch for one engine type is standardized. Also other engine type related main measurements, such as elevation of the eaves, of an engine hall are pretty much constant regardless the project. Empty model layout is designed according to engine hall module size of five to six engines. Using this average engine quantity of one module it is easy to add new boundary boxes or delete ones if the quantity of engines differs from the average. Categorizing assemblies by module is easy to implement by choosing section division related location categories and attaching them to "Assemblies by module" categories.

Structural designers are copying existing model or part of the model to the model layout of a new project. All the object attributes are also imported to the model of a new project. Therefore attaching installation sequence number for assemblies and parts is only required to implement if the objects of a model that is used as a layout for a new model doesn't contain installation sequence numbers, or if new objects are inserted in the model.

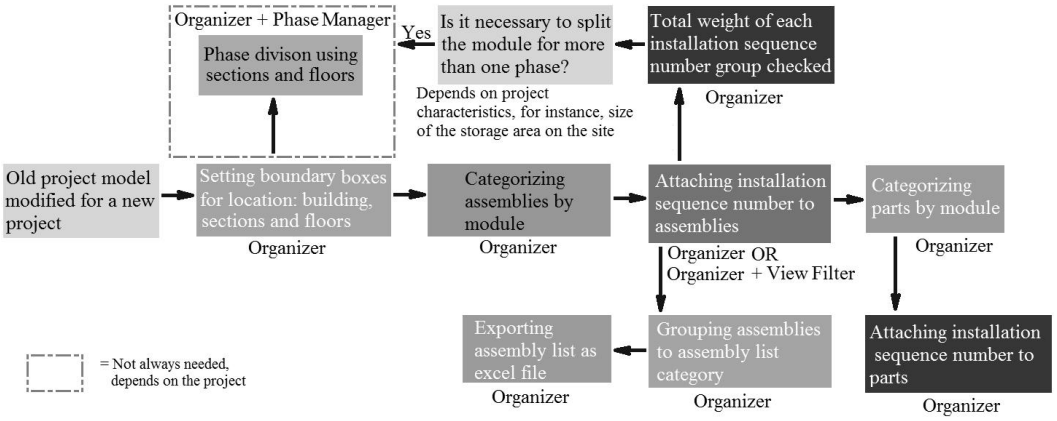


Figure 10.2 *Steps for structural designer to categorize and modify Tekla Structures model, and to crate assembly list with installation sequence number when using Tekla Structures version 20.*

Organizer tool is not available in Tekla Structures 19 or earlier version. Model categorization properties are also more limited in these versions. Still, model can be divided to phases using Phase Manager if required in the project. Weight of each installation sequence number group and need for more detailed than module based phase division is examined by using Lotting tool.

View Filter and manual object attribute input is used for attaching installation sequence numbers to assemblies and parts. Attaching installation sequence number for parts, especially, is more time consuming in Tekla Structures 19 or earlier version compared to version 20. In addition, if phase division of a module is needed you can't use boundary boxes to ease object categorization for phases. Objects must be manually grouped and attached to phases in the Phase Manager. This process is prone to human errors and there is a change that some of the objects are not attached to any phase group.

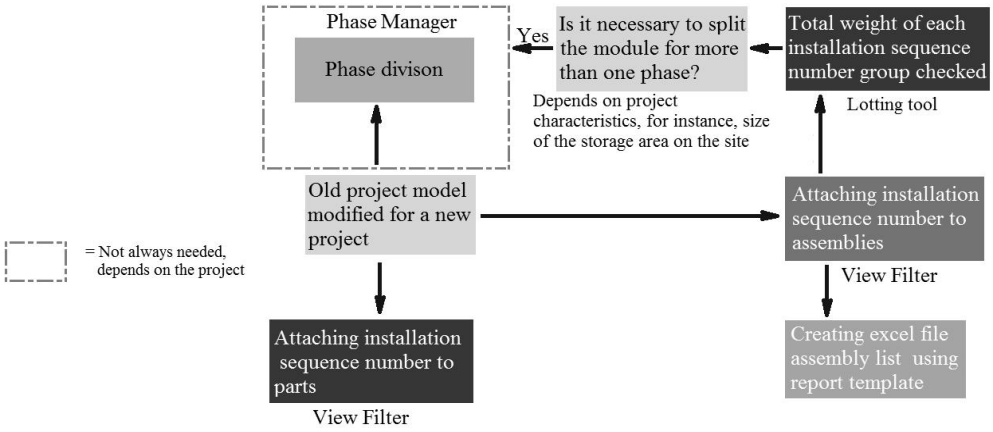


Figure 10.3 *Steps for structural designer to categorize and modify Tekla Structures model, and to crate assembly list with installation sequence number when using Tekla Structures 19 or earlier version.*

Use of the Organizer in Tekla Structures version 20 eases managing assembly and part data in many ways. Main benefit is that it stores categorization of objects which can be used as base for new categorization or if new revisions of an assembly list must be created. In Tekla Structures 19 or earlier version objects can be categorized using desired View Filter settings. These settings can also be saved so that the same categorization can be repeated in different project or if a new revision of an existing document is needed to be created. However, the potential of categorization is higher when using Organizer instead of plain View Filter. By using Organizer you can also inspect all the properties of objects in real time in a form of a list without a need to publish them yet as a report.

10.3 Frame element delivery

Manufacturing drawings and list are delivered for the frame element supplier by the structural engineering company. They are also delivering assembly lists, assembly part lists and MASP list for the supplier. Assembly lists will contain a column for assembly

specific installation sequence number. Frame element supplier will send question for structural designers if they lack information needed for element manufacturing. They can be related to lack or flaw in documentation or design mistakes. Sometimes extra documents are needed to be sent for the supplier.

Besides installation sequence number in assembly lists, packing requirements for the frame element supplier are sent project specifically by the Project Engineer. They can be described in written documents, drawings or e-mail conversations. Furthermore, packing requirements are set in annual agreement between Wärtsilä and the frame element supplier.

When procurement of the building frame is taking place, project engineer will input assembly list data to Logwis according to MASP list division. Frame element supplier in turn will insert packing lists to Logwis. Packing lists and assembly lists can then be printed out from Logwis at the site.

10.4 BIM based installation planning and Tekla BIMsight in site use

Structural design team can make BIM based installation plans and deliver them as note files for the Project Engineer and the Site Supervisor in the design phase of a project. These notes are containing chosen objects with selected view. They can also include markups added in the views.

Site Supervisor is making his own assembly plans and progress reports as slide show slides. Formerly created slides with attached objects are used as layout for new slides of assembly plans or progress reports. Assembly plans can also be used as layouts for progress reports.

Slides are Tekla BIMsight user specific and designed for personal planning and for storing views with attached objects. Assembly plans and progress reports can be delivered for the Project Engineer by creating notes and attaching slide view information to them. All the notes are stored as note files in the cloud project folder.

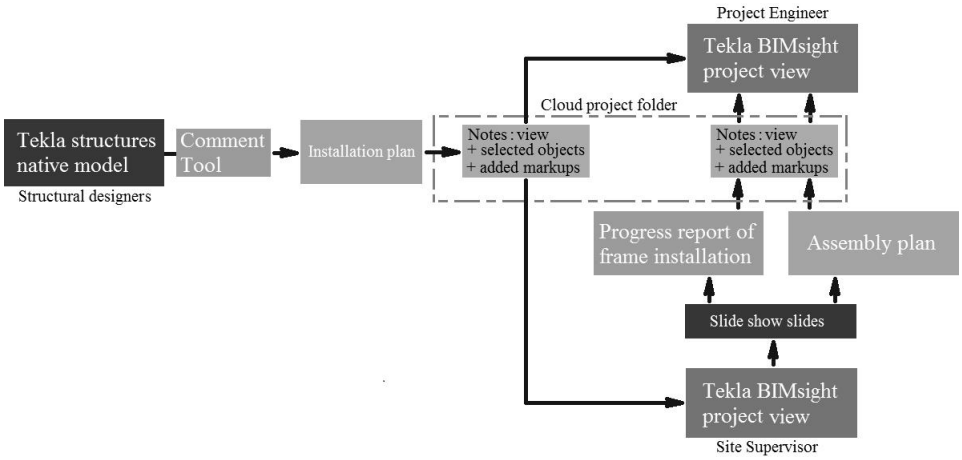


Figure 10.4 *Note file and cloud project folder based sharing of installation plan by Structural Designers, and assembly plan and progress report by Site Supervisor.*

Site Supervisor is managing frame unpacking and installation works by delivering information found in Tekla BIMsight and 2D documents for the construction workers. He is mainly using out-printed packing lists found in Logwis for managing container unloading. Assembly lists are used for both unloading containers and management of frame installation. Installation sequence number data found in Tekla BIMsight can also be used for managing container unloading.

Site Supervisor is primarily using Tekla BIMsight for frame installation planning and management. 2D documents are used if some information needed for installation management is not found in Tekla BIMsight or if it is easier to search the information in 2D document. Since mechanical reference model is attached to Tekla BIMsight project view it can be used for the coordination of civil and mechanical installation works.

Site Supervisor is using information found in Tekla BIMsight for supervision of installation works, for assembly planning and for making progress reports of the frame installation. This can be implemented by grouping and sorting objects in various ways in Objects tab of Tekla BIMsight. Objects can be grouped by selected state, bolt size, ERECTION_CODE, Assembly mark or Assembly/Cast unit Mark. They can then be sorted by Assembly mark, AssemblyWeight, Bolt length, Top elevation, Bottom elevation, Assembly/Cast unit top elevation, or Assembly Cast unit bottom elevation. As a result of aforementioned object grouping and sorting setting, you can manage assembly numbers and assembly weight of selected objects, bolt types, bolt quantities, bolt locations, and approximate packing and installation order. You can also manage part and assembly elevations. Object grouping and sorting settings with data accessed by selected settings are presented in Figure 10.5.

Besides aforementioned ones, there are several other useful object grouping and sorting settings that can be used depending on the case. Deviation in many of these combinations is that they can only be listed in the object browser, not visualized in the model view. This is because full support for assembly level hierarchy is not yet available. At the moment, assembly information must be written for each object of an assembly and looked for through those objects in the object browser in order to visualize the property. [16]

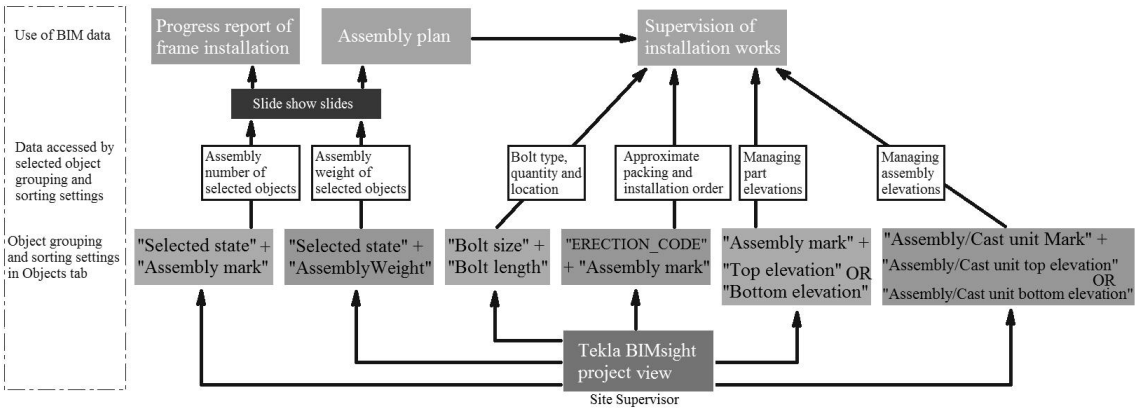


Figure 10.5 *Main applications of Tekla BIMsight data at site and related object grouping and sorting settings in Objects tab.*

11 DISCUSSION AND CONCLUSION

11.1 Evaluation of the research

Results of the thesis are corresponding well to the objectives of the research. Modeling and construction management related general properties of Tekla Strctures and Tekla BIMsight were introduced briefly but accurately so that the reader will get perception of the use of these softwares. Thesis was also specifying the properties of the softwares related to the main-objective and presented them in step-by-step instructions. Step-by-step instructions were written for the use of Structural Designers, Project Engineers and Site Supervisors so that they can create and utilize installation logistics related BIM data.

Constructor's main interests concerning construction management with installation logistics in focus, and procedures of the frame element supplier were introduced in the Chapters 5 and 6. This information was used for defining what kinds of properties were looked for in Tekla Structures and Tekla BIMsight. Validation of the findings was reviewed based on the interview of Structural Designer: It was assessed whether the created system was possible to be implemented by the engineering company. Technical potential and limitations for the system were determined based on this evaluation. As a result of the findings and the interviews, quality standards for modeling process and communication protocols were introduced in the Chapter 10.

Part of the main objective was to formulate a suitable BIM based packing management system and packing order. Right from the start of the research there was a goal to integrate BIM related packing standard if possible to the existing documents used by Wärtsilä. This would prevent more documents to be needed for project management and hence prevent installation logistics related procedures to become more complex. It found out that the most practical way to affect to the way the elements are packed into containers is to define the desired packing order in the assembly list. This could be implemented by adding an installation sequence number for each assembly as an object attribute.

One benefit of using assembly specific installation sequence number is that there is no need for more than one assembly list per module. It also enables continuous packing: elements belonging to one installation sequence number group can be used for filling the empty space in the container containing elements belonging to previous installation sequence group. This information is automatically available for the frame element supplier when assembly lists with installation sequence numbers are used. Therefore, ideally and in simple projects as an installation and schedule management point of view,

there is no need for conversation between the supplier and a Project Engineer whether some elements can be used for filling the empty space in some container.

Chosen installation sequence number grouping is also practical as a frame element manufacturing and packing point of view. As an industrial engineering point of view it is practical to manufacture same kind of elements at the same time. Similar type and size of elements are also usually packed in a same package within a container. The chosen installation sequence number group division is conforming supplier's systems and needs related to element manufacturing and packing. The chosen system is also the best option for Wärtsilä since it most probably doesn't bring much or if any extra cost compared to undefined packing order.

Other part of the main objective was to formulate a suitable BIM based installation logistics and project management system that supports BIM based frame element delivery and packing system. It found out that it is practical to publish a structural and MEP model in Tekla BIMsight project located in cloud folder for project collaboration. BIM based communication can be based on note files saved in project folder and shared between Structural Designers and Project Engineers, and between Project engineers and Site Supervisors.

Using shared cloud folder enhances both design phase coordination and frame installation management. Project Engineers can interact with designers outside design meetings using modeling data. It enables more intense and visual communication between Structural Designers and Project Engineers which will reduce probability of design mistakes. Enhanced communication will also enable more reliable frame element delivery management since both Structural Designers and Site Supervisors can tell their needs and views of frame installation and packing related issues. Structural Designers can make their installation plan and deliver it as note files.

Tekla BIMsight enables more effective information flow between the Site Supervisors and the Structural Designers. Site Supervisors can deliver their assembly plans as note files for Project Engineers and for Structural Designers if needed, and BIM based progress reports for Project Engineers. Structural Designer can then validate structural operability of the assembly plan.

Installation sequence numbers defining the packing order can also be inspected in Tekla BIMsight. Site Supervisor can plan the point of time for frame element unloading and make erection plans based on this data.

11.2 Deviation from the expected results and reliability of the research

Based on the objectives of the thesis, at the beginning of the thesis there was one possibility that it could be easier to track frame elements in the container based on the supplier's input for the model. It would have been possible to attach a container number as an object attribute for each model assembly after the frame elements have been packed by

the supplier. This would have allowed tracking each element based on the assembly specific container number presented in the Tekla BIMsight model that is used at the site.

Instead, it turned out to be more practical just to ensure that the frame element supplier is packing the elements according to the installation order provided by installation sequence numbers. One reason for this solution was that the frame element supplier doesn't use BIM but 2D documents for managing element packing. The selected system was also supported by the fact that you can't take one specific element out of the container when needed and leave others in the container. Virtually in every case all the frame elements are dragged out of the container at the same time and grouped in the laydown area according to the element type.

Interviews had a major role in defining the needs and characteristics of BIM based frame element packing, project management and installation management system. Therefore they were highly affecting on the results of the thesis. It is possible that the interviewed Site Manager or Site Supervisor has only been involved in certain type of projects or worked in couple of countries. Since the way of working varies depending on the site team, project team, contractor and the project country there is some variation in the opinions and answers. The most proper packing and installation order system depends highly on the aforementioned project characteristics and therefore no all-inclusive generalizations can be made.

There are many ways and tools to create assembly lists and manage frame installation using data written in the model objects. Presented tools are meeting the objectives of the research, but some other integrated tools or extension tools could also enhance the modeling process. For example, there are extension tools for easier UDA data attaching work for model parts. Additional extension tool testing was left out of the research to avoid aimlessly expansive structure of the thesis. Assembly list with installation sequence number as a system however is simple to be implemented and not prone to minor errors of structural modeling.

11.3 Limitations of the system

New procedures are always requiring certain amount and time and money to be properly implemented. Therefore BIM technology is reasonable to be integrated for the frame element delivery, site and communication management between project stakeholders only if it is easy enough to be realized. It should also provide obvious benefits compared to 2D documents based project and site management.

Laptops compatible to full and free version of Tekla BIMsight are already used by Project Engineers and Site Supervisors. Therefore staring to use this software doesn't bring any costs except required software training. On the other hand, compatible tablets or mobile phones are creating some costs if they are decided to be introduced. Still, more constrained version of Tekla BIMsight called Tekla BIMsight Note can only be used in iOS or Android devices at the moment.

Note file based project communication enables easier and visually more informative way to deliver issues to other project stakeholders. It also supports project specific and packing order related decision making along with inspection of assembly weights in the Organizer tool or in the Lotting tool. Although note files are easy to create and send they can't be considered to replace all the other forms of communication in the design or installation phase. For example, documents attached to objects in Tekla BIMsight can't be delivered to other Tekla BIMsight users in the project as notes or in other form of BIM data at the moment.

When using shared cloud project folder notes are available for all folder users if these notes are selected to be shared or public. This means that note files can't be applied just for one of the stakeholder that has access to the folder. For example, note file conversations between the Project Engineer and the Site Supervisor are also automatically visible for the Structural Designers. The benefit of this property is that structural design related issues are automatically forwarded to the Structural Designers. The weakness is that also non-structural design related issues are forwarded for the Designers which can be confusing.

Presentation of installation sequence number based packing requirements expressed in the assembly list is easy and quick to implement. Therefore it can be used in the project even if the size of the engine hall or characteristics of the project wouldn't necessary require it. Also boundary box based phase division of an engine hall is easy to implement if the nature of a project requires it.

The introduced BIM based packing management system and packing order is only applying in the delivery and installation works of an engine hall. Still, modular management system with installation sequence number division could be generalized and extended to be concerned frames of all the other main buildings in Wärtsilä's projects. Before that, engine hall related system must be piloted to localize possible errors and needs for improvements. It is most important to manage frame installation and packing of an engine hall at the moment since it is the most significant frame structure at site as quantity of assemblies, money and project schedule point of view.

It is possible to include virtually all information needed for frame element installation in Tekla BIMsight model. Instead, it doesn't currently contain all the functions needed for replacing assembly drawings. Objects must be grouped and sorted in order to have access to attribute data. Therefore, you can't inspect all the data needed for implementing assembly at a glance similarly to assembly drawings. Also dimension lines between objects can't be exported from Tekla Stuctures to Tekla BIMsight. Instead, they must be set manually in Tekla BIMsight model view. In order to fully integrate BIM in site use the software should contain function for more visual representation of assembly data.

Slide views are effective way to create and note files to share progress report information. Benefit in BIM based progress report compared to Excel form one is that you can visually examine the progress. If only Excel is used for managing assembly progress data it is necessary to attach photos for a report. Deficiency in BIM based

progress report is that at the moment Tekla BIMsight doesn't express total weight of selected assemblies or have easy tools for printing data out of the model. Therefore Excel is still needed for summing total weight of selected assemblies and for summing other assembly data. In the future, progress reporting could be based on Tekla BIMsight if aforementioned properties are added in the software.

11.4 Further research

There are still some properties needed to be developed until BIM technology will provide revolutionary benefits on project management compared to conventional 2D document based project management. Still, it is recommendable to introduce construction management related BIM tools for the processes of the company. For the time being, there is not much to further improve in BIM based frame element delivery management. As long as the frame element supplier doesn't use BIM tools for managing deliveries it is not recommendable invest on developing BIM based packing management system further than the presented system.

BIM based communication however, found out to be an effective way to enhance processes both in the design and installation phase of a project. Therefore it could be studied how to further develop communication protocols presented in this thesis to become more suitable for Wärtsilä's needs. It could also be studied if there are more applications for the presented communication tools. Furthermore, it must be studied if these tools could be integrated to other software systems used in Wärtsilä's projects.

Next thing to be studied could also be whether the information provided by thesis and applications of Tekla Structures could be used for BIM based scheduling. Now that the engine hall has been divided to installation sequence number groups and to element groups defined by volumetric areas as boundary boxes in the Organizer tool, it is possible to inspect weight of these groups. This information and other tools besides the Organizer might then be used for more accurate and standardized scheduling of frame installation works.

One focus of the follow-up research could be to study whether it is possible to use progress report information created in Tekla BIMsight for scheduling. Now that both assembly plans and progress reports can be implemented in BIM environment it is easier to visually evaluate if assembly plans equate the actual progress. It can also be reviewed which installations are taking more time than assumed.

Note file based progress report data might be used for creating a database of realized frame installation durations. It could also be studied if assembly numbers and steel kilos could be used for making the database more accurate. This data might then be utilized outright for frame installation scheduling: note files can be delivered from Tekla BIMsight to Tekla Structures and Tekla Structures can be linked to Microsoft Project used for scheduling in the company.

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